Big Qualicum River Salmon Development Project, Volume I: A Biological Assessment, 1959-1972

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ABSTRACT

Fraser, F.J., E.A. Perry and D.T. Lightly. 1983. Big Qualicum River Salmon Development Project, Volume I: A biological assessment, 1959-1972. Can. Tech. Rep. Fish. Aquat. Sci. 1189: 198 p.

This report describes the physical aspects of the Big Qualicum River Development Project designed primarily to increase chum freshwater survival; analyses the degree of flow and temperature regulation achieved; describes stream improvement techniques; assesses the response of chum, coho, chinook and steelhead to management efforts by comparing pre - flow control (1959 - 1963) and post-flow control (1964 - 1972) biological parameters of these species; documents the degree of success of the two artifical spawning channels compared to the natural but regulated river environment; and reviews relevant aspects of the life history of above fish species.

Key words: chum, chinook, coho, steelhead, Big Qualicum River, spawning channels, salmon.

RÉSUMÉ

Fraser, F.J., E.A. Perry and D.T. Lightly. 1983. Big Qualicum River Salmon Development Project, Volume I: A biological assessment, 1959-1972. Can. Tech. Rep. Fish. Aquat. Sci. 1189: 198 p.

Le présent rapport décrit les aspects physiques du Projet de développement de la rivière Big Qualicum, conçu principalement pour accroître la survie du saumon kéta en eau douce; il analyse également le degré de régulation du débit et de la température, élabore les techniques d'amélioration de cours d'eau, évalue la réaction des saumons kéta, coho et quinnat et de la truite arc-en-ciel aux efforts de gestion, en comparant les paramètres biologiques de ces espèces avant (1959-1963) et après (1964-1972) le contrôle du débit, fournit de l'information sur le degré de succès des deux frayères artificielles par rapport à l'environnement fluvial naturel, mais régularisé, et examine les aspects pertinents du cycle vital des espèces de poisson susmentionnées.

Mots-clés: saumon kéta, saumon quinnat, saumon coho, truite arc-en-ciel, rivière Big Qualicum, frayères artificielles, saumon.

INTRODUCTION

The Big Qualicum River Development Project, located on the east coast of Vancouver Island (Fig.1), was designed in the early 1960's to increase the production of Pacific salmon in that system by enhancing freshwater survival. The major species in the system, chum salmon (Oncorhynchus keta), was to benefit the most since some 95% of the total pre-adult chum mortality occurs during the freshwater stage.

Wickett (1952) pioneered the attempts to increase freshwater survival of salmonids at Nile Creek, Vancouver Island, whereby fertilized chum and pink eggs were hand-buried in a controlled flow channel. Egg-to-fry survival of both species was higher than in the adjacent river, with a maximum enhancement of 48 times estimated for the 1949 brood chum salmon. At Jones Creek, a tributary to the Fraser River, the construction of a spawning channel with controlled flow was directly related to increase in the population of pink salmon spawners from 400 fish in 1955 to 2,119 fish in 1959 (Fraser and Fedorenko 1983). More significantly, however, the egg-to-fry survival rates for the three broods of pink salmon studied at Jones Creek during that period were 36.0%, 32.3% and 49.9%; these were high rates compared to the previously reported rates in British Columbia ranging from less than 1% to 23% (MacKinnon et al. 1961).

The control and modification of the entire Big Qualicum River system was undertaken to serve as a pilot study for future salmonid management programs. Intensive examination of the salmonid response to enhancement measures has continued since 1959, when a counting fence was installed just above the river mouth. Control of river flow and construction of spawning channel No. 1 was completed in 1963. In 1967, a second spawning channel was added. Extensive stream improvement of the Big Qualicum River and of the four relocation areas (man-made channels through which the main river was diverted to make way for construction of Hunt's Creek channel and dyke) was initiated in 1964. In 1968, pilot hatchery facilities were added to the system which partially affected the flow and temperature control requirements and the salmonid production.

This report describes 14 years (1959-1972) of operational data in the Big Qualicum River system centered on chum, coho and chinook salmon, and less so on steelhead, with the 1959 to 1962 broods serving as pre-development controls. The degree of flow and temperature regulation achieved and the effect of these controls on the system are analyzed. The response by salmonid populations to management efforts is assessed, and relevant aspects of the life history of anadromous fish are reviewed. This report also documents the degree of success of the two artificial spawning channels compared to the natural but regulated river environment.

Some of the data used in this report are cited as (DFO, unpublished data) and are available from the Department of Fisheries and Oceans, Big Qualicum River file No. 5903-85-05.

DESCRIPTION OF THE BIG QUALICUM RIVER SYSTEM

Most of the 150 km^2 of the Big Qualicum River watershed are drained by the headwaters channelled by the upper Qualicum River into Horne Lake and by the Big Qualicum River which enters the Strait of Georgia (Fig.1). Drainage into Horne Lake accounts for 110 km^2 of the total watershed area while the only major tributary between Horne Lake and the sea, Hunt's Creek, drains 19 km^2. The Big Qualicum River watershed shares two features with other systems on the east coast of Vancouver Island - extensive logged areas and susceptability of water flow to seasonal freshet or drought conditions governed by precipitation. Annual mean precipitation ranges between 152 cm and 178 cm, of which only about 11% occurs during June to September.

UPPER QUALICUM RIVER

The headwaters of the Big Qualicum River system arise in the wooded, mountainous, southern portion of the Beaufort Range whose partially metamorphosed sedimentaries rise to almost 1,200 m and are snow-capped in winter. The sides of the upper Qualicum River valley are steep with voluminous flash runoffs occurring during periods of heavy precipitation. In an average year, of the total discharge from the Big Qualicum River system into the sea, approximately 78% to 80% (61% in a flood year) enter the west end of Horne Lake via upper Qualicum River.

HORNE LAKE

Horne Lake stretches in an east-west direction and measures approximately 6.0 km by 1.2 km; its surface area is approximately 7.8 km^2 (Fig.1). Mean lake depth is approximately 52 m

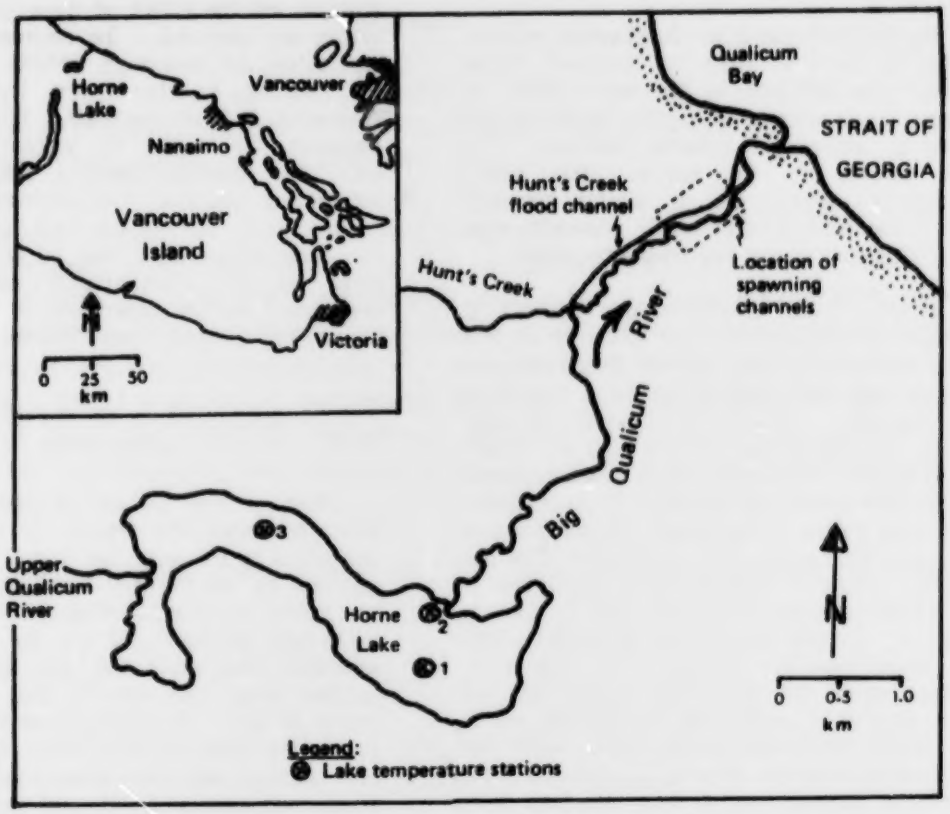


Fig. 1. Location of Big Qualicum River salmon development project.

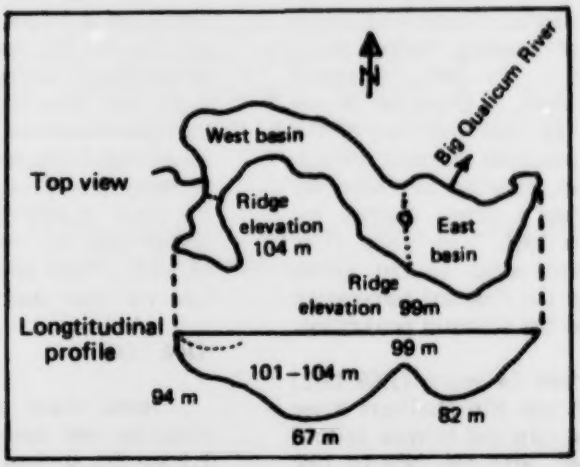


Fig. 2. Location of east and west basins in Horne Lake (schematic; depth is given in meters above M.S.L.)

and the lake surface is about 119 m above mean sea level (M.S.L.). Most of the total lake volume of about 18,400 hec-m is above an elevation of 104 m above M.S.L. A ridge with a minimum elevation of 99 m above M.S.L. runs in an approximately north-south direction through an island in the centre of the lake forming east and west basins (Fig. 2). Another ridge, with an elevation of 104 m above M.S.L. runs in an east-west direction across the narrow channel of the lake, just south of the upper Qualicum River inlet (Fig. 2).

The temperature regime of Horne Lake is typical of temperate zone lakes. During winter (November-May) the lake is essentially isothermal; in summer (May-September) a thermocline develops; breakdown of the thermocline usually starts in October. As in other Vancouver Island lakes, biological production of Horne Lake is low due to high precipitation and the erosion-resistant bedrock of the drainage area. Northcote and Larkin (1956) reported that total dissolved solids in Horne Lake were 44 ppm and that its populations of plankton, fish and bottom fauna were low.

BIG QUALICUM RIVER

The Big Qualicum River, located approximately 60 km northwest of Nanaimo, flows northeast from Horne Lake for 11 km before entering the Strait of Georgia (Fig. 1). From the outlet at Horne Lake, the river drops 31.9 m in 1.2 km in a succession of rapids and four falls which are impassable to salmonids. The remainder of the river course passes through a progressively wider coastal plains valley consisting of quadra sands. Riverbed width ranges from 18 m to 21 m with a fairly uniform bed slope of 0.6% except for short steeper lengths.The riverbed and banks consist mainly of sand and gravel. The vegetation, mainly brush and alder trees, is important for bank stabilization.

HUNT'S CREEK

The headwaters of Hunt's Creek are located on the steep slopes of a mountain ridge about 2.4 km north of Horne Lake in the vicinity of Mount Mark (Fig. 1). Hunt's Creek originates close to the 700 m level, but drops 457 m in the first 2.4 km. The creek then flows more gently to its confluence with the Big Qualicum River, 6.4 km below Horne Lake. (Fig. 1).

Hunt's Creek is important in the Big Qualicum River Development Project because significant numbers of coho and steelhead spawn in the creek, and because its freshets could seriously impair attempts to regulate flow in the mainstream.

DESCRIPTION OF SALMONID RESOURCE

The Big Qualicum River system supports all five species of Pacific salmon, but only chum (Oncorhynchus keta), coho (O. kisutch) and chinook (O. tshawytscha) are abundant, with chum accounting for about 90% of the anadromous adult returns (Fig. 3, Table 1). The pink salmon (O. gorbuscha) population was supplemented by transplants in 1963 and 1964 but failed to establish itself above earlier levels (Walker and Lister 1971). Sockeye salmon (O. nerka) are present but rare. These fish most likely originate from kokanee in Horne Lake but alternately may represent Big Qualicum River spawning and rearing fish or fish from a race of "creek" sockeye known to exist in Englishman River a short distance to the south. In addition, steelhead trout (Salmo gairdneri) inhabit both the Big Qualicum River and Hunt's Creek.

Chum adults enter the Big Qualicum River during late September or mid-October through December; chinook during August or September through November; and steelhead from November to April. Peak spawning occurs during late October for chinook, late November for coho, early December for chum, and early March for steelhead.

Chum and coho fry start to emigrate in early March and are usually present in the system until late June or early July (but in some years they were observed until August). Chinook fry emigrate from early March to early May when a shift to fingerlings is apparent. Coho smolts are observed throughout the coho fry downstream migration period, and steelhead smolts emigrate during late March through June.

Cutthroat trout (Salmo clarki) are also found in the Big Qualicum River. Brown trout (S. trutta), apparently present in the 1930's, were not observed in recent years. They may have originated from transplants in Little Qualicum River, 16 km to the south, or from unreported stocking in Big Qualicum River. Other indigenous species include the aleutian sculpin (Cottus aleuticus), the prickly sculpin (C. asper), the threespine stickleback (Gosterosteus aculeatus)

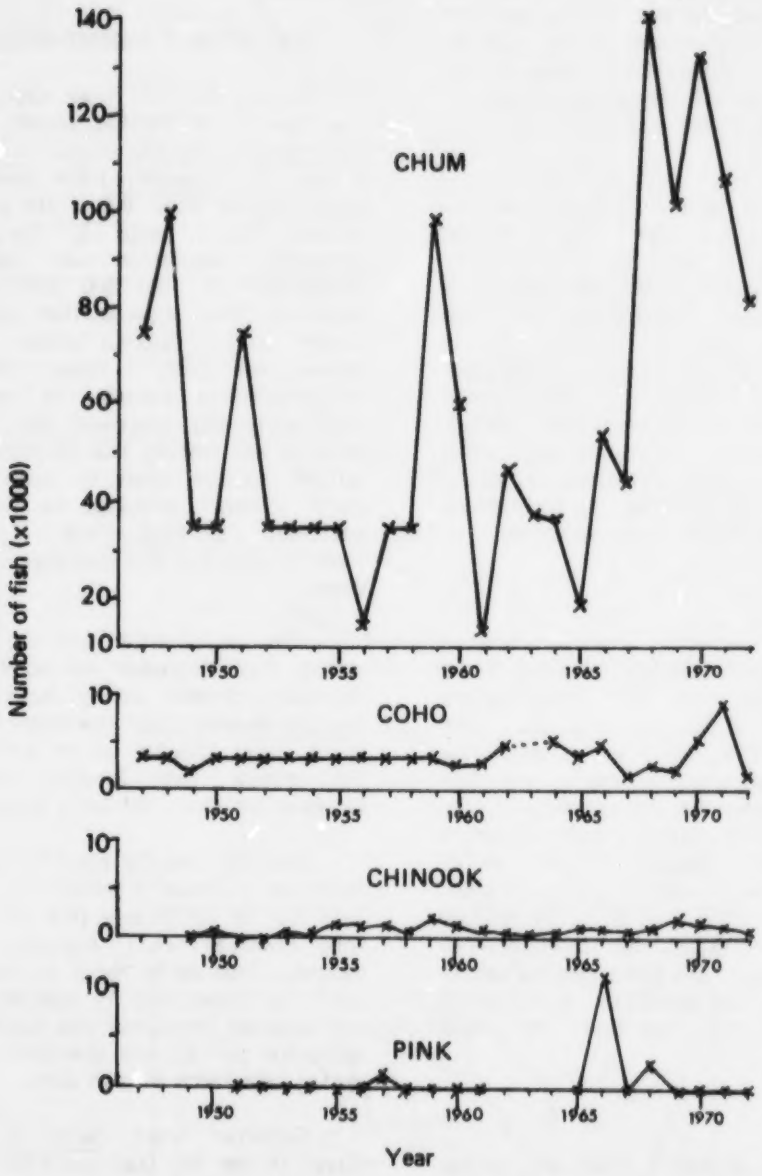


Fig. 3. Annual escapement of chum, coho, chinook and pink salmon to Big Qualicum River system, 1947 – 1972.

Table 1. Estimated annual escapements of chum, coho, chinook and pink salmon to Big Qualicum River system, 1947-1972[a].

Year	Chum[b]	Coho	Chinook	Pink	Total
1947	75,000	3,500	---[d]	---	78,500+
1948	100,000+[c]	3,500	---	---	103,500+
1949	35,000	1,500	200	---	36,700+
1950	35,000	3,500	750	---	39,250+
1951	75,000	3,500	400	400	79,300
1952	35,000	3,500	200	200	38,900
1953	35,000	3,500	750	75	39,325
1954	35,000	3,500	750	200	39,450
1955	35,000	3,500	1,500	25	40,025
1956	15,000	3,500	1,500	200	20,200
1957	35,000	3,500	1,500	1,500	41,500
1958	35,000	3,500	750	25	39,275
Mean (1947-1958)	45,400+	3,300	800	300	49,660+
1959	98,500	3,600	2,400	11	104,500
1960	59,900	2,600	1,600	25	64,125
1961	13,800	2,900	1,100	1	17,800
1962	47,100	4,600	800	0	52,500
1963	37,700	1,400+	600	1	39,700+
1964	36,500	5,200	800	0	42,500
1965	18,900	3,800	1,300	75	24,075
1966	53,800	5,000	1,200	11,900	71,900
1967	43,200	1,600	900	4	45,700
1968	140,400	2,600	1,300	2,500	146,800
1969	101,000	2,200	2,400	0	105,600
1970	132,300	5,500	1,700	25	139,525
1971	106,000	9,100	1,400	25	116,525
1972	80,500	1,600	900	25	83,025
Mean (1959-1972)	69,300	3,900[e]	1,300	1,050	78,050[e]

[a] Counting facilities installed in 1959.
[b] Includes spawning channel fish from 1963 onward.
[c] Underestimated.
[d] No data.
[e] Excludes 1963 incomplete escapement.

and the Pacific lamprey (Entosphenus tridentatus). All Big Qualicum River fish are excluded from Horne Lake by the falls.

DESCRIPTION OF THE BIG QUALICUM RIVER DEVELOPMENT PROJECT

BIOLOGICAL POTENTIAL OF BIG QUALICUM RIVER SYSTEM

Preliminary studies of Big Qualicum River salmonid populations in 1958 and 1959 revealed that actual fish production was well below potential production. The primary reason for this was the occurrence of floods and droughts at least once every ten years. Wickett (1959) surveyed the streambed and, using the direct relationship between permeability of gravel and the optimum number of spawners to maximize fry production (Wickett 1958), predicted the potential sustainable spawning population and catch. In the 12 years prior to 1959, escapements of chum, coho and chinook to Big Qualicum River averaged 45,400, 3,300 and 800 fish respectively (Table 1). An optimistic estimate of the corresponding commercial catch of chum was 100,000. Wickett (1959), using chum salmon as an example, suggested that simply by controlling river flow, maintenance of this stock size would be ensured. Also, any expected future gains in escapement would not be subjected to severely fluctuating environmental conditions and therefore would be sustained. With some streambed improvements to accomodate a spawning stock of 200,000, the sustained catch would be 500,000 chum. Finally, Wickett (1959) predicted that if the discharge was controlled and spawning conditions below Hunt's Creek confluence were improved to the standards above the creek, a total of 500,000 chum could spawn in the system and support a fishery of 1,700,000.

SITE SELECTION

The Big Qualicum River was considered to be a superior site for a controlled flow project, compared to other river systems in B.C., because it combined the following advantages:

1. the Big Qualicum River was a major producer of Pacific salmon and trout for sport and commercial fisheries;

2. the river supported native runs of most species of Pacific salmon, so that project success was not dependent on the establishment of a species foreign to the watershed (failure of pink salmon transplants in Robertson Creek, Vancouver Island, emphasized the importance of this feature; Lim and Barrett 1982);

3. the river had extreme variations in flow that resulted in low fry survival; consequently production of adults was below potential;

4. Horne Lake appeared to be ideally situated to act as a storage reservoir to maintain the flows required in the river, and to prevent floods which could damage the spawning beds;

5. a design of the outlet works at Horne Lake appeared possible that would allow a certain amount of temperature control in the river downstream;

6. only one major tributary, Hunt's Creek, was likely to cause flooding, and it could be diverted from the Big Qualicum River at reasonable cost;

7. the lakeshore property surrounding Horne Lake was underdeveloped so that no excessive cost for water storage acquisition was anticipated; and

8. access by road and rail to the area was very good compared to other areas in British Columbia.

CONTROL OF BIG QUALICUM RIVER FLOW

The control of Big Qualicum River discharge involved three steps:

1. blocking the normal outlet of Horne Lake with an earth-fill dam;

2. passing water from Horne Lake via a tunnel to the river bed at the base of the second falls; and

3. diverting the excess flow from Hunt's Creek.

Horne Lake

The gate house on Horne Lake (Fig. 4) was equipped with three intakes at elevations of 94 m and 108 m above M.S.L. and another near lake surface (Figs. 4 and 5). The valve house at the

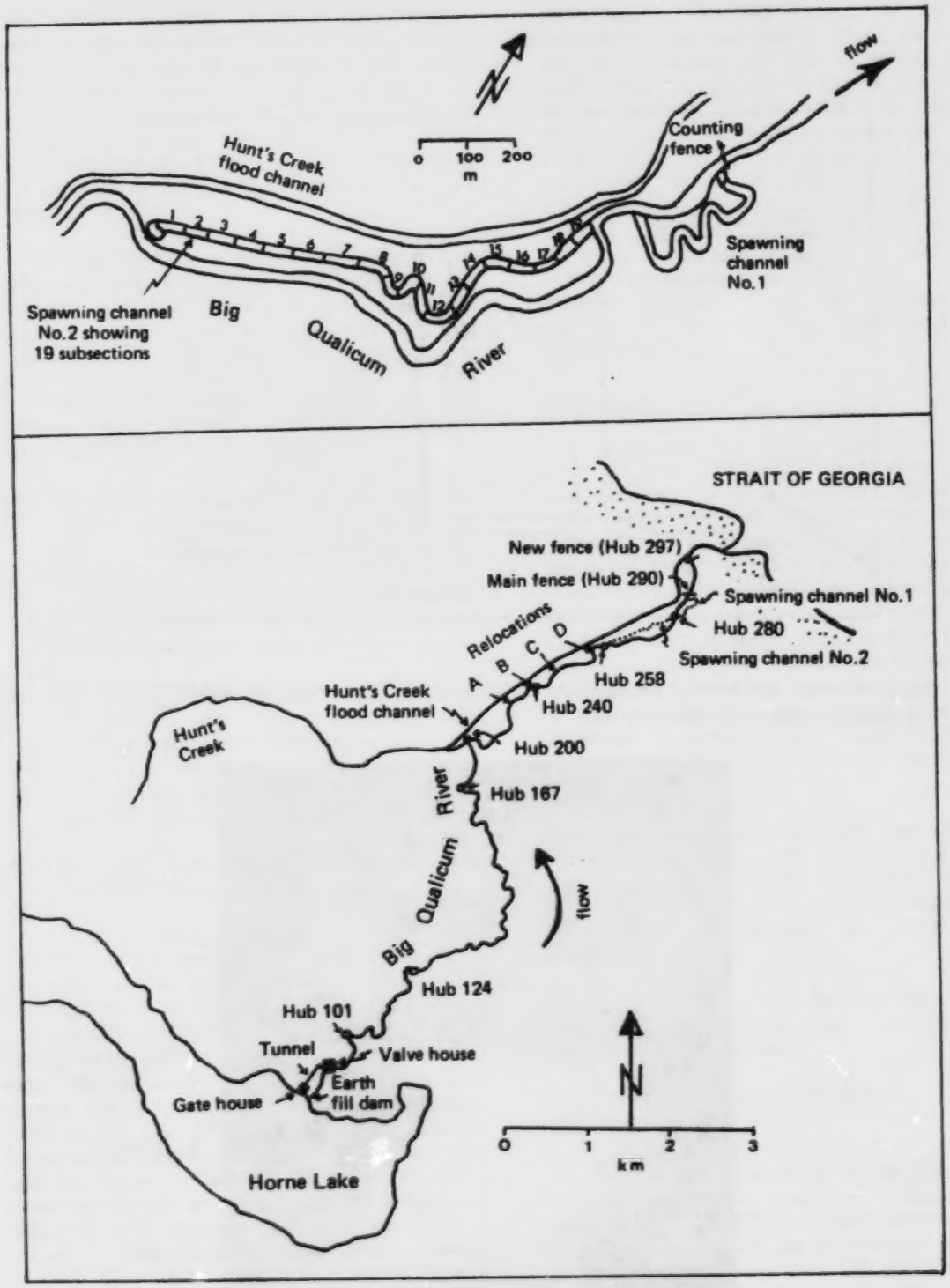


Fig. 4. Big Qualicum River system showing main features of the development project; top insert shows detail of spawning channels No.1 and No.2.

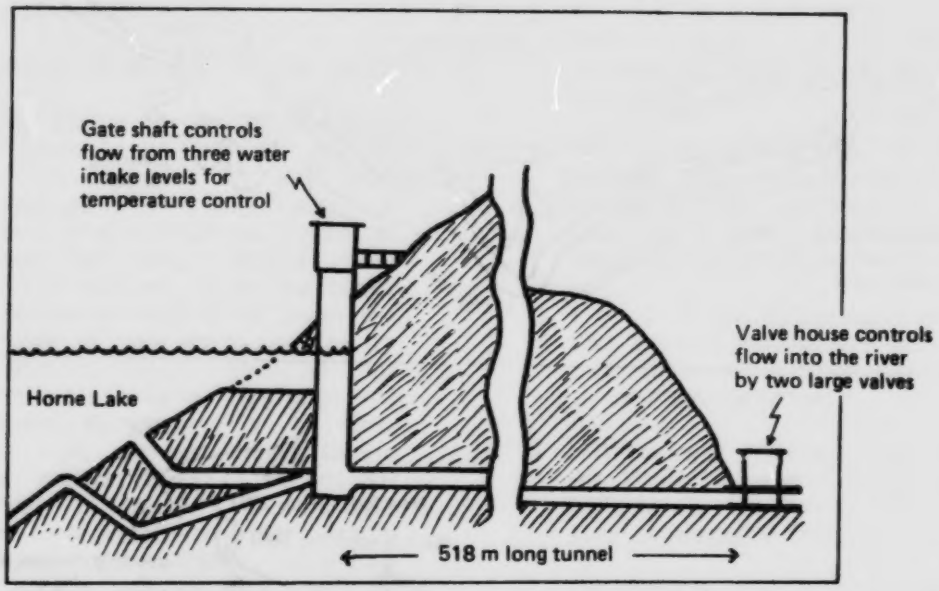


Fig. 5. Horne Lake water intake system which controls flow and water temperature in the Big Qualicum River (diagrammatic).

Fig. 6. The valve house at the second falls below Horne Lake regulates discharge with two hollow cone valves.

end of the outlet tunnel regulated discharge with two hollow cone valves (Fig. 6). At the normal lake surface elevation of 119 m above M.S.L., water volume was 18,400 hec-m of which 13,100 hec-m were available to the three intakes. Flow control works allowed for a water elevation of 125 m, but since flooding of lakeshore and cottages would occur at this level, maximum operational height was set at 121 m. Details of the engineering design are reported by Clay and Fahlman (1962).

An operating rule curve for discharge from Horne Lake into Big Qualicum River (Fig. 7) was designed as a function of water levels in Horne Lake which are critical in flood prevention, and seasonal flow requirements that would allow sufficient hypolimnial lake volume to be available for temperature control (Lister and Walker 1966). The following additional considerations had to be satisfied:

1) biological requirements for the spawning, rearing and incubation of all salmon and trout species, including (from 1968) juveniles in artifical rearing facilities (spawning flows of 4.2 m^3/sec. to 7.1 m^3/sec and minimum summer flows of 1.1 m^3/sec were considered as major criteria);

2) engineering requirements for stream improvement and flow adjustment to facilitate any future construction;

3) recreational use of Horne Lake (May 1 to September 15); and

4) desirable flows for steelhead fishermen (February 1 to April 15).

To obtain the storage capacity required for the flow control project, an annual fluctuation in lake depth of about 10 m was required. The seasonal timing of these controlled fluctuations was an inverse function of the expected precipitation patterns (Fig. 8). Low lake levels were required in the fall to contain the heavy winter precipitation, while higher levels were required in the spring and summer to maintain above normal (pre-flow control) flows in the Big Qualicum River. The fall schedule involved a maximum elevation of 111 m by August 1 (1 to 1966), 111 m by September 30 (1967), and 113 m by October 15 (1968 onward). These three different critical dates were fundamental variables between three operating curves used during the project and reflected progress in understanding interactions among the various factors. For example, the August 1 deadline for the 111 m water height, observed during 1964 to 1966, resulted in low lake levels during the camping and boating season, and lead to erosion of the beach area, its inaccessability to boaters and general aesthetic deterioration. It also meant that only 17 m of water submerged the lowest intake pipe (at 94 m elevation) and that thermocline depths in excess of 17 m would eliminate any possibility of temperature control. The final revision of the flow curve optimized conditions relative to both these factors while satisfying the other criteria. Minimum tolerable flows in September were included in the event that lake levels were unavoidably low.

Hunt's Creek

To ensure that flash floods from Hunt's Creek did not upset controlled flows in the Big Qualicum River, a low dam was constructed on the creek approximately 0.5 km upstream from the junction of the streams. The dam diverted all excessive flows into a 4 km long, artificial flood channel which paralleled the Big Qualicum River along its north bank to a point near tidewater where it merged with the river (Figs. 4 and 9). A culvert through the dam allowed flows as high as 1.4 m^3/sec over the spawning area between the dam and the confluence with the mainstem. An earth fill dyke separated the flood channel from the Big Qualicum River and served as an access road.

Adult salmon were excluded from the flood channel by a concrete drop structure and barrier dam at its downstream end (Fig. 10). This was modified by 1970 to allow adults to migrate into the Hunt's Creek through the flood channel entrance.

Flow in the Big Qualicum River was partially controlled by November 1963, and was fully controlled by August 1964.

CONTROL OF THE BIG QUALICUM RIVER TEMPERATURE

The flow control scheme in the Big Qualicum River was expected to result in increased minimum summer flows and higher summer temperatures in the river, the latter due to diversion of Hunt's Creek waters which were about 5°C cooler than the main river (Fig. 11, 1963 data). The increased minimum summer flows would result in reduced

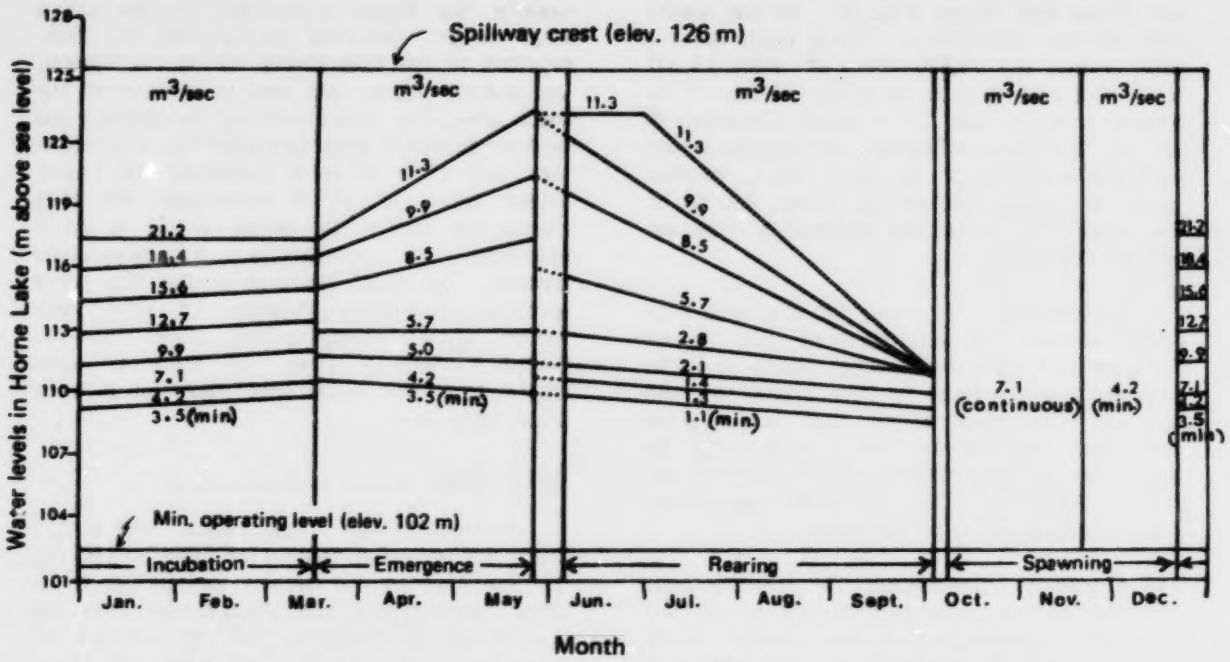


Fig. 7. An operating rule curve for water discharge from Horne Lake into Big Qualicum River as a function of seasonal flow requirements and water levels in Horne Lake.

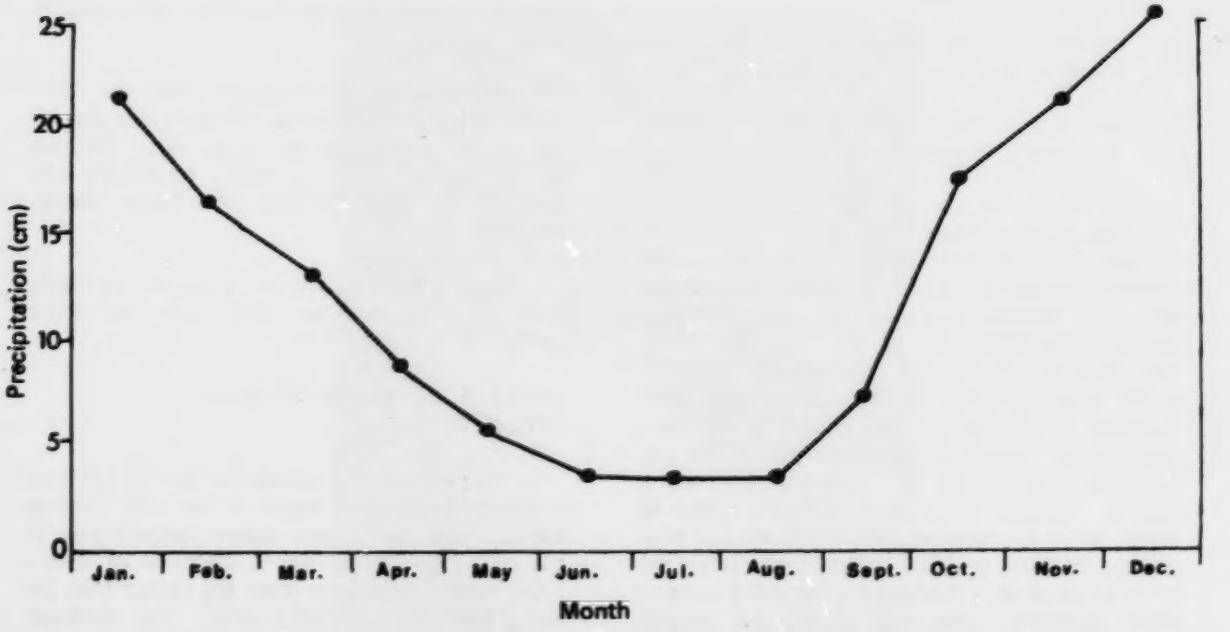


Fig. 8. Monthly precipitation pattern at Big Qualicum River (data from 1930 to 1972 at Cameron Lake, 4 km S.E. of Horne Lake).

Fig. 9. The Hunt's Creek flood channel and dyke following the north side of the valley.

Fig. 10. Culvert and barrier dam at the downstream end of Hunt's Creek.

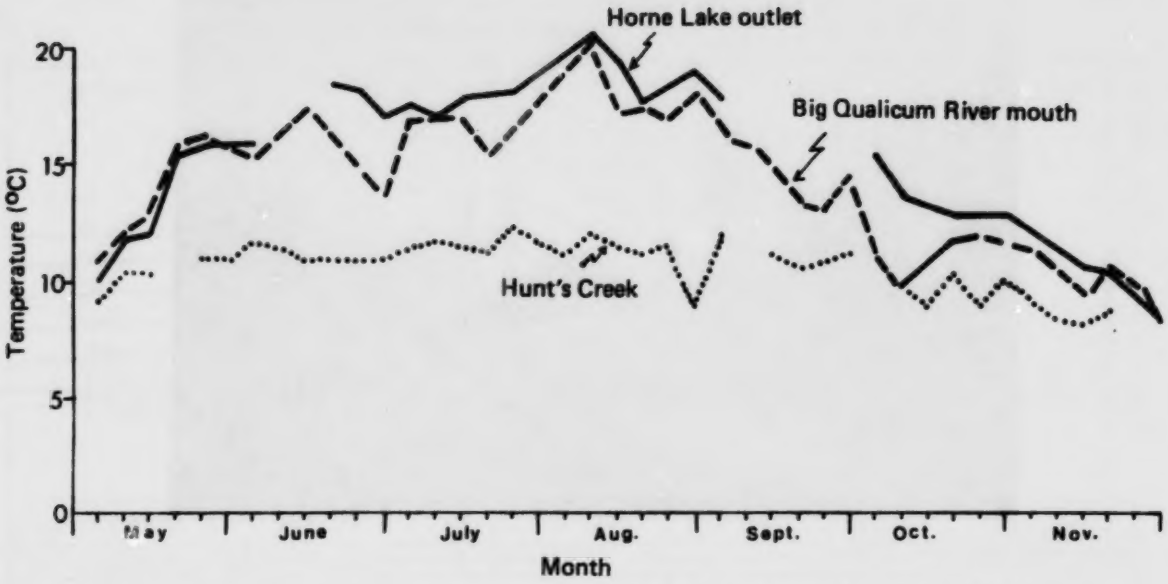


Fig. 11. Water temperature at Horne Lake outlet, Big Qualicum River mouth (camp bridge), and in Hunt's Creek, measured at 5-day intervals during May through November 1963.

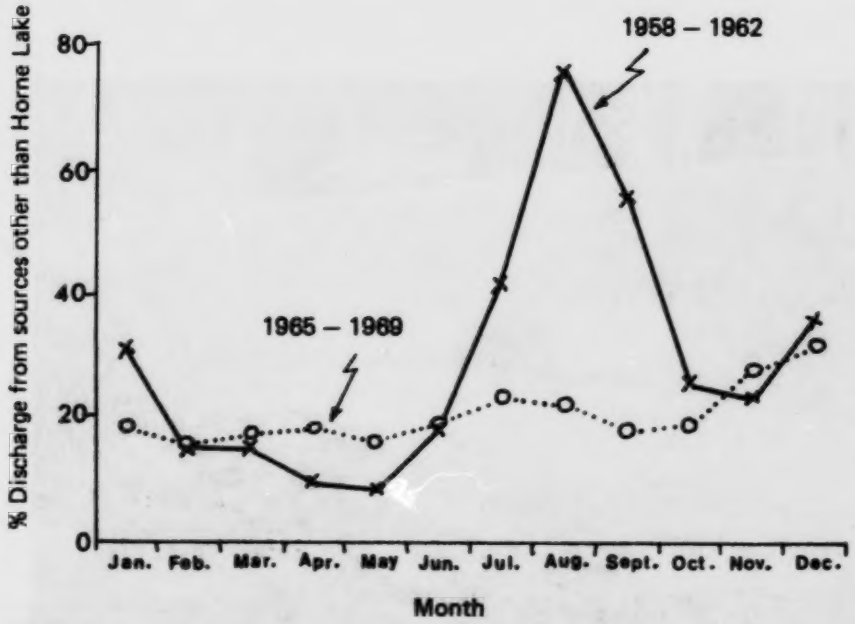


Fig. 12. Proportion of Big Qualicum River monthly discharge from secondary sources before (1958 – 1962) and after (1965 – 1969) flow control.

influence of groundwater and other drainage flows (Fig. 12), and in reduced heat losses from evaporation and conduction due to lowering of surface to volume ratio. The expected temperature increase could lower freshwater survival of rearing juveniles. In order to counteract such adverse effects, water temperature was manipulated by drawing water from different depths in Horne Lake.

The design of three lake intakes at three different elevations (Fig. 5) incorporated the predicted withdrawal depths required to maintain natural temperature regime in the river, and was based on the 1959 to 1961 thermal data for Horne Lake and the lower river (Fig. 13). The maximum intake depth of 94 m elevation above M.S.L. allowed the largest possible reservior of hypolimnial water within cost restraints.

Temperature in the Big Qualicum River was manipulated moderately from 1964 to 1967, and extensively from 1968 when hatchery facilities became operational.

SPAWNING CHANNELS

Two spawning channels were constructed at the Big Qualicum River in 1963 and 1967 (Fig. 4).

Spawning channel No. 1 operated from 1963 to 1969 and was designed for natural spawning mainly by chum salmon and for incubation of transplanted pink salmon eggs (in 1963 and 1964, eyed pink eggs totalling 11.6 million were transplanted into two sections of the channel; their survival averaged 39%; Walker and Lister 1971). Channel No. 1 was located immediately upstream from the main fence on the east bank of the river (Fig. 4) and received flow from the river through a controlled intake. The channel provided 2,800 m^2 of spawning gravel for approximately 2,000 chum salmon. It was 730 m long and 6 m wide, with an average water depth of 46 cm over the spawning area and a mean channel slope of 0.09%. The designed flow was 1.7 m^3/sec at a velocity of 64 cm/sec. Spawning gravel, 2 cm to 10 cm in diameter, was deposited to a depth of 60 cm. Seven pools, 18.3 m long and 1.2 m deep, were located throughout the channel. Impervious inverts located at each end of the pools forced water to rise out of the gravel ensuring aeration. Spawning channel No. 1 was converted into a rearing facility in 1969.

Spawning channel No. 2 started operation in 1967 and was designed solely for chum salmon production. Channel No. 2 was located on the opposite bank of the Big Qualicum River from channel No. 1, with its outlet just above channel No. 1 and 213 m upstream from the main fence (Fig. 4). Channel No. 2 received flow from the river through a controlled intake and provided 11,950 m^2 of spawning gravel for approximately 20,000 chum salmon. It was 1,036 m long and 12 m wide, with 1.5 m gravel shoulders. Washed gravel, 2 cm to 15 cm in diameter, was deposited to a depth of 45 cm to 60 cm. Experience with channel No. 1 resulted in the introduction in channel No. 2 of a settling basin at the channel inlet (Fig. 14) and a steeper gradient of 0.2% over the spawning area. Channel No. 2 contained 19 sections, each 52 m long (Fig. 4), and all but the most upstream section contained at the upper end a full width pool 3.0 long and 0.9 m to 1.5 m deep. At the downstream end of each section, an impervious wooden invert control with a 7.6 m wide opening was constructed with the lower sill at the level of the upchannel gravel. These invert controls forced some of the water to rise out of the gravel and make a 15 cm drop into the next pool. Spawning dividers installed at selected invert controls in later years ensured a more uniform spawning distribution (see below). A counting fence at the downstream end of channel No. 2 (Fig. 15) allowed for complete enumeration of adult and fry migrants.

STREAM IMPROVEMENT

Compared to southeast Alaskan streams where spawning occurs in 35% to 59% of the total streambed area (based on data from McNeil 1965), only 20% of the wetted area in Big Qualicum River was judged satisfactory for spawning. Major factors contributing to this low spawning quality were gravel compaction and high average gradient (0.6%) which limited spawning to stream margins in many sections. From 1965 onward, much effort was spent overcoming these conditions to increase the spawning area and thereby accommodate the projected management goals for the Big Qualicum River system of over 150,000 chum spawners. Stream improvement work is detailed in later sections.

METHODS

ADULT ENUMERATION

Generally, complete fish counts were obtained, except occasionally between 1959 and 1963 when high floods made fish enumeration difficult. The main counting fence consisted of

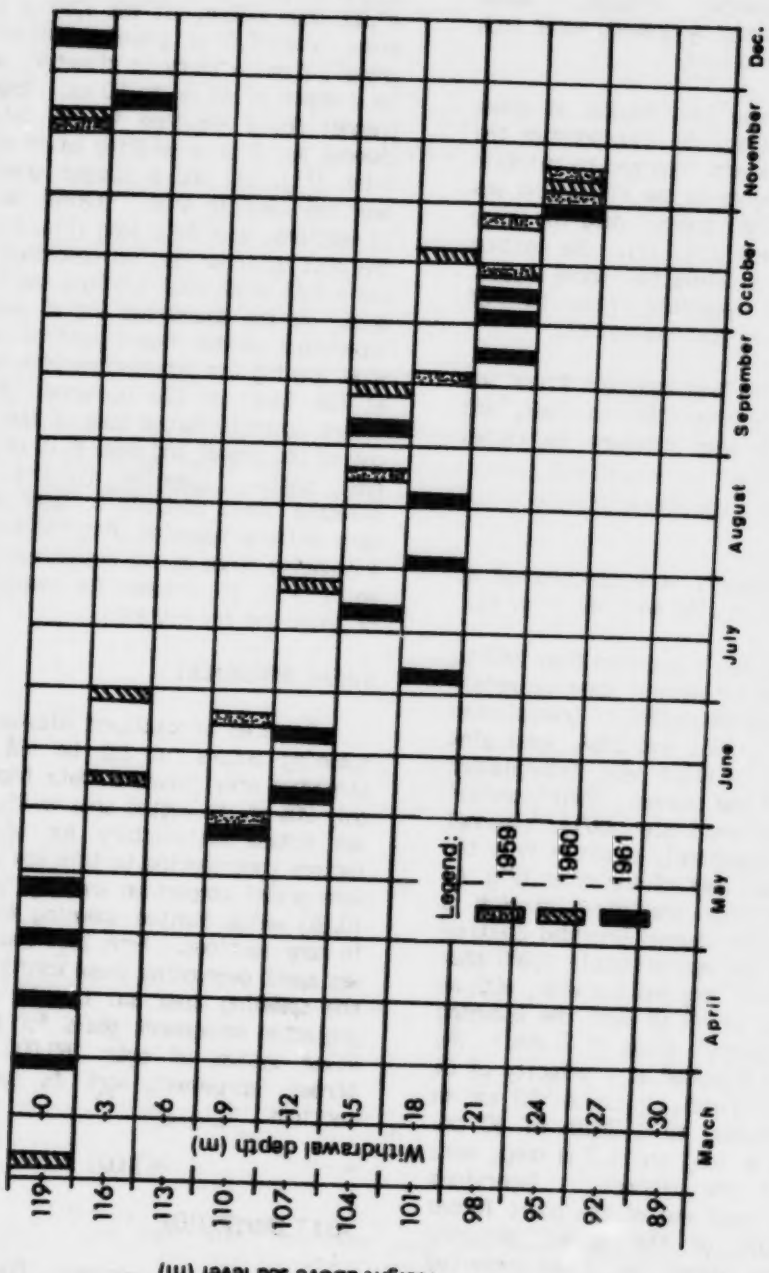


Fig. 13. The levels of Horne Lake at which some water would have to be drawn in order to match the lower river temperatures in 1959, 1960 and 1961.

Fig. 14. Water diversion and intake system in spawning channel No.2; the settling basin and channel are seen in the background.

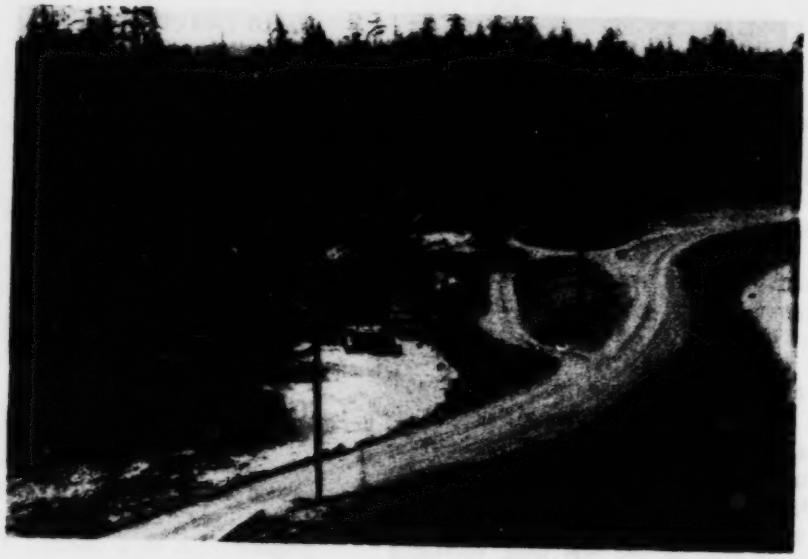


Fig. 15. Outlet of spawning channel No.2 showing the counting fence; Hunt's Creek flood channel and dyke are seen on the right; Big Qualicum River flows in from the left.

a weir across the full width of the river at hub 290 (Fig. 4). Panels in the fence could be raised, allowing fish to pass through and over sheets of white flashboard which increased counting efficiency by observers stationed in a tower on the bank (Fig. 16). Adults for sampling or egg taking were diverted at the weir into a live trap which, after completion of channel No. 1 in 1963, was also used to regulate fish entry into that channel. The 11.0 m x 13.7 m concrete live trap had a water volume capacity of 184 m^3, sufficient for 1800 adults.

Another counting weir was situated at the downstream end of channel No. 2 (Fig. 15). When this weir was open, migrating adults could freely enter channel No. 2 or the upper river. In 1970, the construction of a weir on the river at hub 280, slightly upstream from channel No. 2 outlet (Fig. 4), made it possible to direct all the fish from a particular portion of the run into that channel.

From 1959 to 1969, a live trap was operated on Hunt's Creek just upstream from its confluence with the Big Qualicum River. Fish entering the creek were caught in this trap, counted and released to continue upstream. During 1970, the original outlet of Hunt's Creek was closed. Since then fish have entered the creek through the flood channel (Fig. 4), and their population was estimated from spawner distribution counts. Spawner distribution counts were also used to estimate chum escapement below the main fence (hub 290).

Chinook escapement to the river until 1969 was estimated by spawner distribution counts. Later, fence counts were made; these were supplemented with distribution counts if the early part of the run entered the river before the fence was installed.

Steelhead escapement estimates to the river above the counting fence were incomplete prior to 1964/65, and only those adults which returned before the end of adult chum migration were counted. After 1964/65, the total steelhead escapement was monitored using either fence counts or spawner distribution counts. Thus, while the beginning of the steelhead migration was recorded in all years of the study, escapement estimates and dates for 50% completion and total completion of the run were available only from 1964/65 onward.

SPAWNING DISTRIBUTION

Since 1959, spawning distribution in the Big Qualicum River was recorded from the base of the fourth falls to the river mouth, a distance of 10.6 km. Counts were made while walking the river at various times throughout the spawning period. Counts were scored between hub markers, then grouped into seven river sections which ranged in length from 0.3 km to 3.7 km (Table 2). Total spawner population was estimated by plotting counts against time for each river section, integrating the area under the curve, and calculating the number of spawners in each section according to the formula:

$$\text{No. spawners} = \frac{\text{Area under curve x No. spawner days/Unit area}}{\text{Redd life}}$$

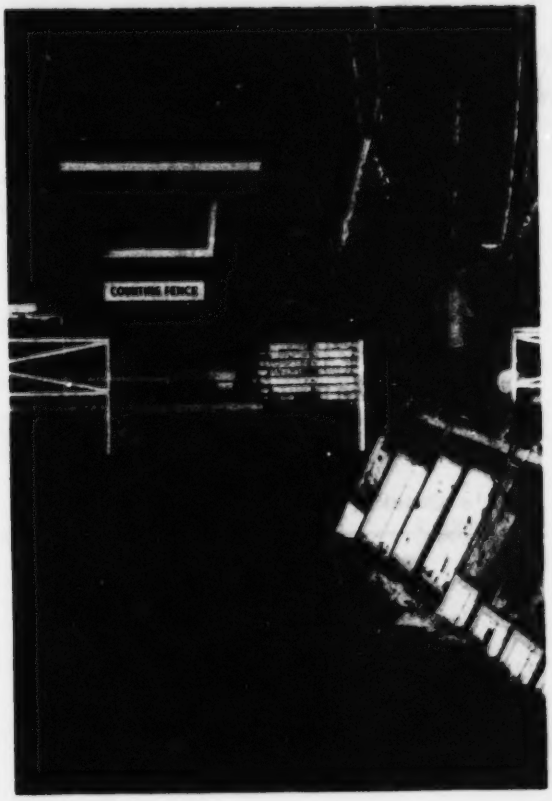
Redd life of 6.5 days (chum data, see below) was used to adjust for repeat counts.

Water clarity, climatic conditions, timing and frequency of spawner counts, and variation in redd life contributed to variation in counting efficiency and in accuracy of population estimates. During the early years of the project, spawner distribution counts consistently underestimated fence counts (Table 3). Since 1967, distribution counts were made at a higher frequency resulting in better population estimates (Table 3). This was especially true for chum spawning below the main fence; while the 1959 to 1963 estimates below the fence may be low by as much as 50%, those made in later years were probably within 20% of the actual numbers.

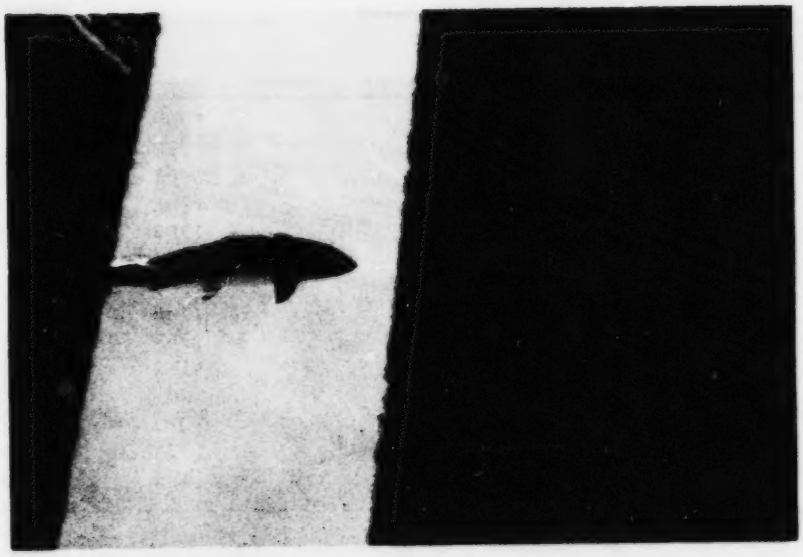
Channel No. 1 spawning distribution of chum was studied in 1966. Fish were enumerated daily from bank towers situated at 13 sites in the channel (Fig. 17). These sites were each subdivided by rope grids suspended about 30 cm above the water surface. Channel No. 2 spawning distribution of chum was recorded since 1968 by daily counts of fish on redds in the 19 channels sections (Fig. 4).

ADULT SAMPLING

Dead fish in the spawning area and those washed against the weirs were sampled for age, length, sex, fecundity and egg retention. Live trapped fish were sampled for age, length, sex and fecundity at the main fence (hub 290) since



(a)



(b)

Fig. 16. View of the main counting fence during adult enumeration (a). Salmon are counted as they pass over white flashboard (b) by an observer stationed in a tower on the bank.

Table 2. Big Qualicum River section defined for the analysis of salmon spawning distribution.

Section	Hubs (see Fig. 25)	Length (km)
1	100 - 123	1.8
2	124 - 147	1.9
3	148 - 167	1.6
4	168 - 173	0.6
5	200 - 281	3.7
6	282 - 290	0.3
7	291 - 304	0.6
Hunt's Creek		2.0

Table 3. Frequency of annual chum observations above and below the main fence, and the effect of increased enumeration effort on the accuracy of chum spawner counts estimated by spawner distribution versus fence counts at Big Qualicum River, 1959 - 1972.

Above fence			Below fence	
Year	No. observations	Above fence spawner distribution count to fence count (%)	Year	No. observations
1960	1	7.1	1959	4
1965	1	35.5	1960	5
1962	2	44.9	1961	6
1964	2	24.4	1962	3
1959	3	30.1	1963	7
1966	3	81.4	1964	13
1961	4	53.4	1965	8
1971	5	103.2	1966	7
1963	6	56.8	1967	8
1967	6	114.4	1968	11
1968	10	80.6	1969	14
1969	11	86.3	1970	25
1972	11	116.2	1971	18
1970	15	115.5	1972	26

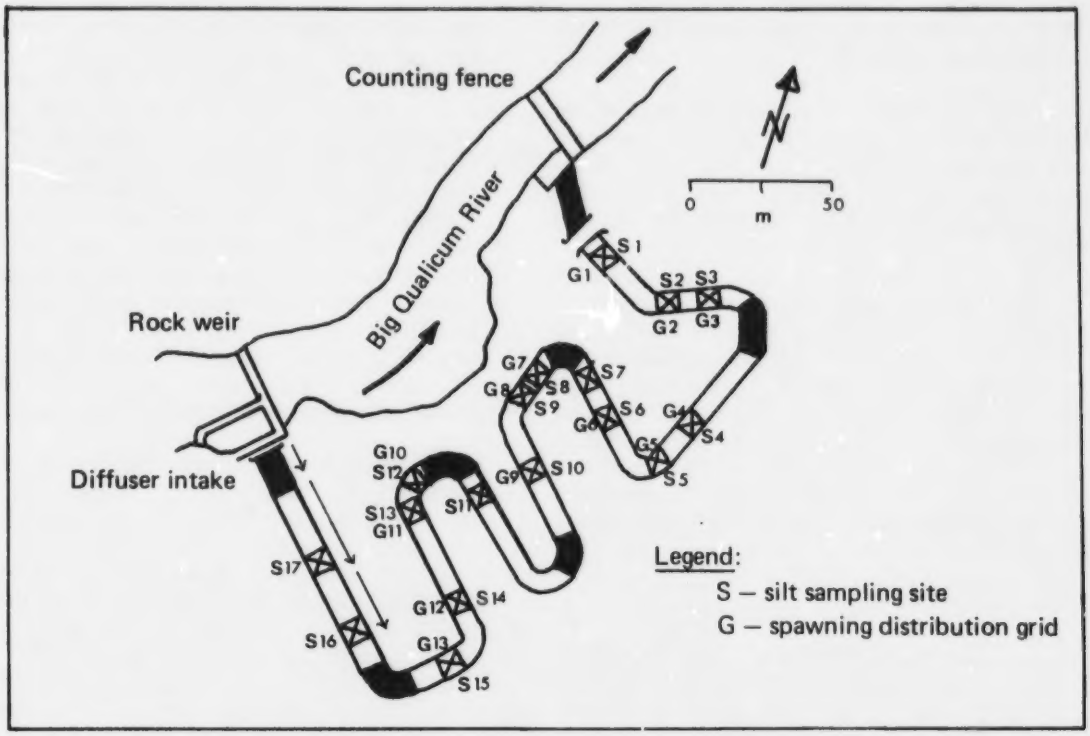


Fig. 17. Spawning channel No.1 showing sampling sites in 1966.

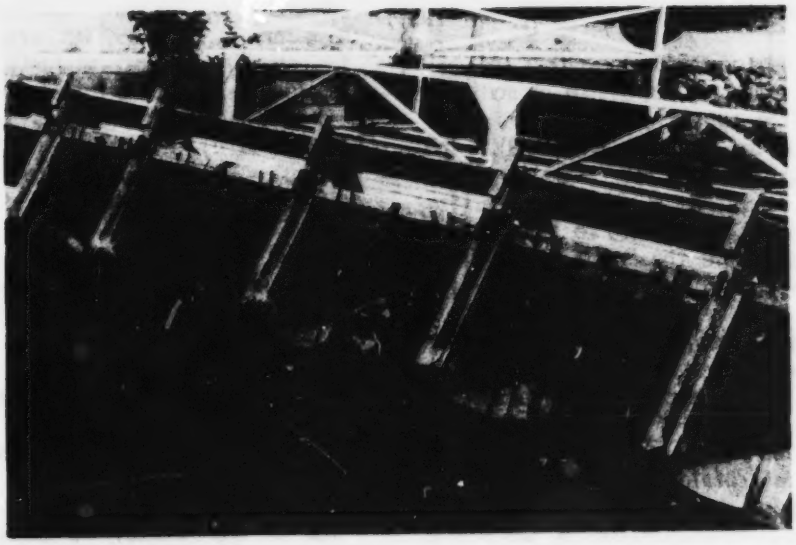


Fig. 18. Modified Wolfe traps used for juvenile enumeration. The water flows over stoplogs anchored to the stream bottom, and drops approximately one foot into the traps.

1970. Age/scale analysis was carried out in the DFO Vancouver laboratory.

Samples of adult chum escaping to the Big Qualicum River or caught by commercial fishermen were examined for missing fins from 1967 onward. Since 1969, all fish handled including chinook, coho and steelhead were examined for missing fins.

Fish lengths were measured from mid-eye to fork of tail (1959-1961), from postorbital to fork of tail (1962-1965), and from postorbital to hypural plate (1966 onward). All length data were standarized by conversion to postorbital-hypural plate measurements using empirically determined regression equations (Append. 1). The correlation coefficients were highly significant, indicating that this method is reliable.

JUVENILE ENUMERATION

Independent enumerations were made of juvenile salmon migrating from the Big Qualicum River (1960 onward, but 1963 onward for coho juveniles), channel No. 1 (1964-1968), channel No. 2 (1968 onward), Hunt's Creek (1963-1970) and the flood channel (1963 onward). Coho fry production in Hunt's Creek could not be determined prior to 1963, since the creek juveniles were included with the river counts above hub 290. From 1963 to 1970, coho juveniles migrated through Hunt's Creek or flood channel outlets and were enumerated separately. Since 1970, all Hunt's Creek coho juveniles migrated through the flood channel.

The gear used in all locations and all years, with one exception, consisted of modified Wolfe traps fitted to the counting weirs (Fig. 18), as described by Lister et al. (1969). The actual number and size of these traps varied as improvements were implemented and the sample size requirements changed. From 1963 to 1970, a fyke net was used to sample the Hunt's Creek flood channel migrants.

The numbers of chum, coho, pink and chinook fry, and some early migrating chinook fingerlings were estimated by volumetric conversion (1960), direct count (1961-1967) and wet weight conversion (1968-1973). Volumetric and gravimetric data obtained each night were converted to total numbers caught for each species by subsampling and determining the volume or weight per fish of the different species and the species composition of the catch. Individual sorting of the fry catch necessitated reduction in the size of the traps from 30 cm to 15 cm during the peak of the runs to keep numbers manageable. Prior to 1970, traps at the main fence (hub 290) were monitored separately but since then, they have all emptied into a common trough. Thus, up until 1970, catch size could be reduced by fishing fewer traps. When a greater proportional catch was desired, stoplogs or louvered panels were inserted in the main fence to divert more flow through the sections containing traps. Coho and steelhead smolts and all except the early migrating chinook fingerlings were enumerated by direct count.

Several parameters were required to convert catch figures to downstream totals. If some traps were not operated during peak periods, the efficiency of active traps relative to the inactive ones was determined. Similarly, correction factors were required if stoplogs or louvered panels were added to the gear. These factors were all in addition to the basic trapping efficiency of the catch gear. Juvenile enumeration is described more fully in Appendix 2. The type of gear used, trap catches and trap efficiencies for all the enumeration sites and all species are available in the DFO Big Qualicum River file No. 5903-85-Q5-a.

JUVENILE SAMPLING

Fry quality studies were conducted to identify any differences which might affect survival between fish produced in artificial compared to natural spawning environments. Nose-fork lengths and wet weights were sampled for spawning channel migrants captured at the appropriate outlet weir, mainstem river migrants captured at the main fence (1960-1967) or hub 280 (1968 onward), and Hunt's Creek migrants (1963 onward). Condition coefficient (K = weight (mg) x 100/length $(mm)^3$) was also determined.

In addition, in 1971, a swim tunnel consisting of an 8.5 cm diameter plexiglass tube with a test length of 110 cm (Fig. 19; Thomas et al. 1964) was used to compare the stamina of chum fry from channel No. 2 and the river. Fish were confined to the test area by terminal electrical fields. A standard number of 10 chum fry were introduced to the test area with the electrical fields at 2 to 3 volts. After sealing the hatch and acclimatizing the fish for 15 minutes at a flow of approximately 3 cm/sec, velocity was increased to 28 cm/sec. Time until 20%, 40%,

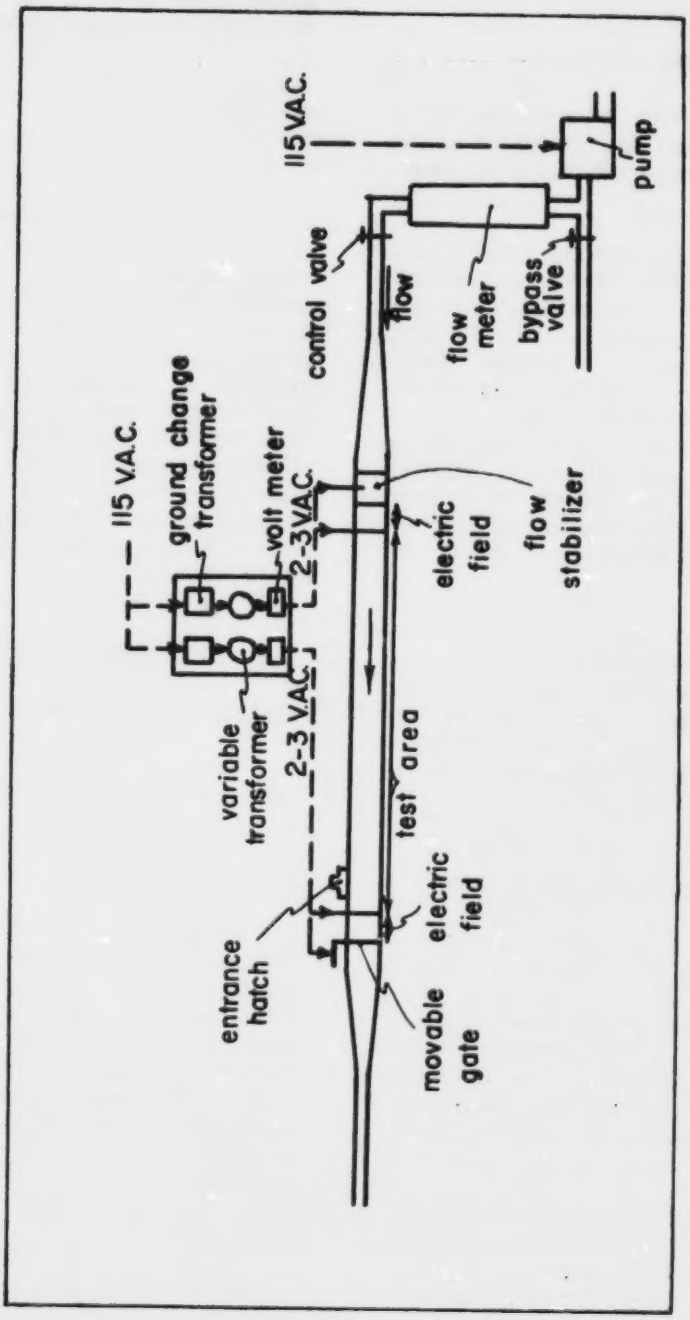


Fig. 19. Swim tunnel apparatus.

50%, 60%, 70%, and 80% of the fish population could not hold their position was recorded to the nearest 0.01 minutes. Three sets of 10 fish from each source were tested daily. Tests were run for 28 days.

JUVENILE MARKING PROGRAMS

Two juvenile marking programs (excluding normal hatchery releases) were carried out at the project site, one program for each species (chum and coho).

The most extensive marking program was designed to assess the contributions to fisheries and escapement of chum salmon originating in the river and the spawning channels. Four fin mark combinations were used: adipose (Ad), adipose-right ventral (AdRV), adipose-left ventral (AdLV) and adipose-anal (AdAn). During the program, AdRV and AdLV marks were used to differentiate between wild river and spawning channel fish. AdAn clips were applied only to reared chum, while Ad clips were applied to river fry of the 1964 brood and to reared fry of the 1967 and 1968 broods.

Hatchery incubated coho fry from the 1969 to 1971 broods were transplanted into Hunt's Creek in an attempt to increase coho production. During these experiments a portion of the transplants were fin marked to determine their survival to migrant smolts; downstream catches of fry in 1972 and of smolts during 1971 to 1974 were examined for marks.

The marking techniques are described in Appendix 3.

PHYSICAL SAMPLING

Temperatures in Horne Lake were recorded at three locations (Fig. 1) and various depths using a bathythermograph (1959-1962) or a thermistor probe (1962-1970). In addition, thermographs were maintained at several stations along the Big Qualicum River including:

1. Horne Lake outlet (1959-1963);
2. camp bridge, 1.2 km above the river mouth (since 1959); and
3. Hunt's Creek outlet (1962-1963 and since 1970).

Discharge from the Big Qualicum River was measured intermittently since 1956 and continuously since 1959 at the Water Survey of Canada Station 8HB located on the logging bridge 90 m downstream from the main fence (hub 290) (Fig. 4). Discharge from the upper Qualicum River was measured from 1958 to 1962. The surface level of Horne Lake was monitored since 1959 with a staff gauge located near the intake.

Sediment content in the gravel (sand, silt and clay) and oxygen concentrations in the interstitial water were measured during January to March 1966, at 17 sites in spawning channel No. 1 (Fig. 17). At each site, five oxygen samples, 180 ml each, were obtained with a large syringe from a depth of 20 cm at equal intervals across the width of the channel. Oxygen was measured using an unmodified Winkler procedure. Samples of 120 ml were taken with the same syringe between adjacent pairs of oxygen sample locations for sediment content determination. These samples were preserved with formalin. Total sediment was measured as volume after allowing the sample to settle for one hour in a graduated cylinder. Particle size analysis was conducted by Coast Eldridge Co. Ltd. using sieve sizes of 2.38 mm, 1.19 mm, 0.59 mm, 0.28 mm, 0.15 mm and 0.07 mm.

RESULTS AND DISCUSSION

BIG QUALICUM RIVER TEMPERATURE AND FLOW REGIMES

Flow and temperature regimes in the Big Qualicum River changed considerably after flow control came into operation in 1963.

Flow regimes

The project succeeded in sustaining higher mean summer and lower mean winter flows, but more significantly, it eliminated the extreme high winter and low summer discharges (Fig. 20, Append. 4). Maximum daily flows each year since 1963 were 14 m^3/sec to 27 m^3/sec, compared to 37 m^3/sec to 91 m^3/sec recorded during the pre-flow control period (Table 4) and 300 m^3/sec recorded on December 2, 1958. Minimum daily flow each year since 1963 was 0.9 m^3/sec, compared to 0.4 m^3/sec recorded during the pre-flow control period (Table 4).

Not all of Big Qualicum River discharge was controlled. While the input from Hunt's Creek was limited to 1.4 m^3/sec after flow control and was completely stopped in 1970, inputs from ground water, seepage through sand banks and surface runoff were not affected. However, the

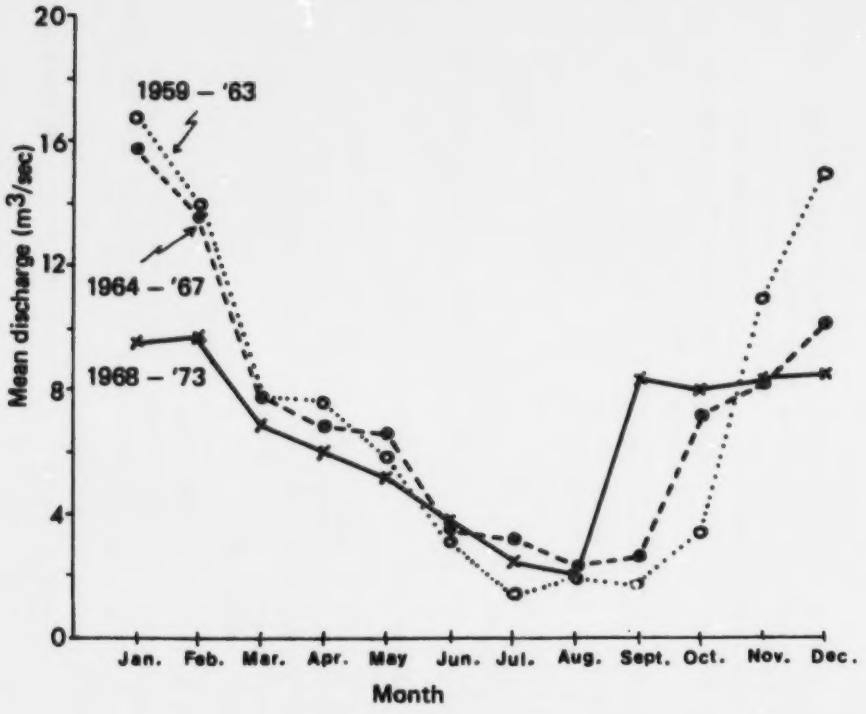


Fig. 20. Mean monthly discharge in Big Qualicum River measured near river mouth (camp bridge) in the pre-flow control (1959 – 1963), flow control (1964 – 1967) and temperature control (1968 – 1973) periods.

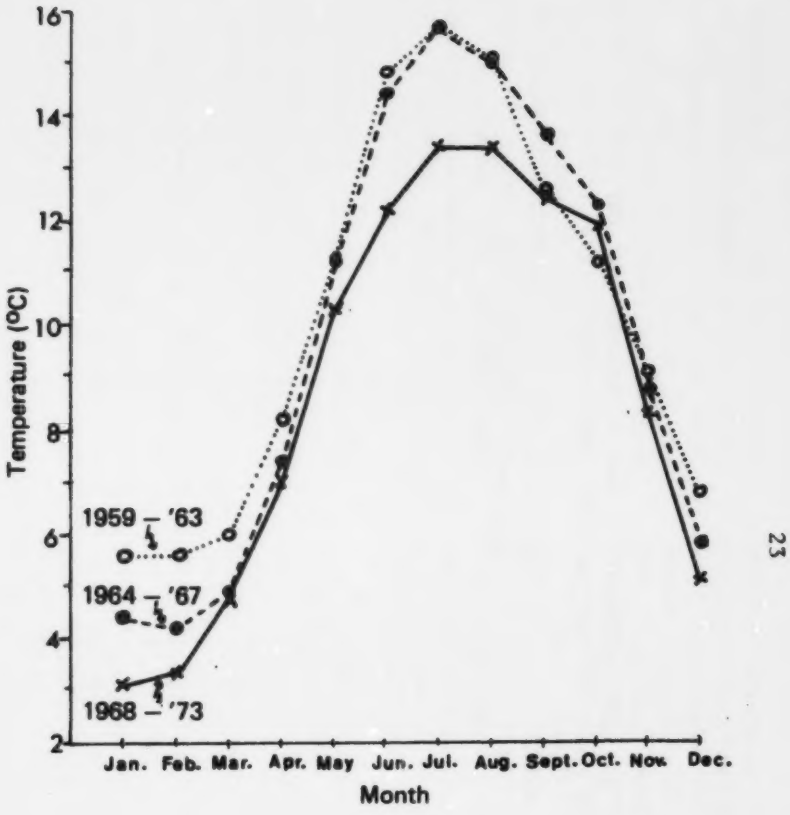


Fig. 21. Mean monthly temperatures in Big Qualicum River measured near river mouth (camp bridge) in the pre-flow control (1959 – 1963), flow control (1964 – 1967) and temperature control (1968 – 1973) periods.

Table 4. Annual maximum, minimum and mean discharges per day recorded near the mouth of Big Qualicum River, 1959 - 1973.

Year	Discharge (m^3/sec)		
	Maximum	Minimum	Mean
1959	60.9	1.0	6.9
1960	36.8	0.7	7.2
1961	90.6	0.4	8.9
1962	37.9	0.9	6.7
1963	56.6	0.7	8.4
1964	22.7	0.9	7.9
1965	18.8	1.7	5.4
1966	24.1	2.7	8.1
1967	24.1	1.5	7.8
1968	23.2	2.1	8.2
1969	23.8	3.5	7.9
1970	14.3	1.5	4.6
1971	23.6	1.9	7.1
1972	21.6	1.6	5.4
1973	26.8	1.7	6.7

Table 5. Chum spawning area available in the Big Qualicum River and spawning channels downstream from hub 124, 1964 - 1969.

Year	Area expansion[a] (m^2)	Total chum spawning area in river[b] (m^2)	Spawning channels[c] (m^2)
1964	---	33,500	2,800
1965	20,900	54,400	2,800
1966	5,800	58,500	2,800
1967	19,400	99,400	12,000
1968	15,300	114,700	12,000-14,000
1969	15,960	129,300	12,000-14,000

a) See Append. Tables 10-1 to 10-3 for details.
b) 1964 - 1964 survey data;
1965 - 1964 survey + 1965 improvements;
1966 - 1966 survey including 1966 improvements;
1967 - 1966 survey (hub 124-203; hub 284 - mouth)
+ 1967 survey (hub 203-281)
+ 1967 expansion
(note: hub 281-284 not included);
1968 - 1967 spawning area + 1968 expansion;
1969 - 1969 survey data including 1969 expansion.
c) Channel No. 2 spawning area increased to 14,200 m^2 by 1970 due to bank spawning.

total secondary input (ie. other than from Horne Lake) was significantly reduced as shown by the difference between discharge at the lake outlet and the river mouth. In the pre-flow control period (1958-1962), the secondary input accounted for 30% of the total Big Qualicum River flow compared to 20% during the post-flow control years (Fig. 12, Append. 5), with much of the decrease attributed primarily to partial diversion of Hunt's Creek water down the flood channel. In particular, after flow control, the secondary input contributed only 22% to the August flow compared to 76% during the pre-flow control years (Fig. 12, Append. 5).

Temperature regimes

Three distinct temperature regimes were experienced in the Big Qualicum River (Figs. 21 and 22, Append. 6):

1) natural, pre-flow control conditions (to 1963);
2) manipulation of the flow to duplicate natural conditions (1964-1967); and
3) extensive temperature control (1968 onward).

During the pre-flow control years, river temperatures at the Horne Lake outlet generally matched temperatures at the lake surface (Append. 7). The 1961 data typify the pre-flow control temperature regime where summer temperatures at the river mouth were often 3°C to 5°C cooler than temperatures at the Horne Lake outlet (Fig. 22, Append. 8). The heat loss along the river course was due to conduction and radiation at night, evaporation, and secondary inputs of cooler water such as Hunt's Creek. For example, in late July 1961, temperature at the lake outlet reached 24°C but was only 16.5°C at the river mouth (camp bridge).

During the post-flow control years, temperature in the Big Qualicum River was governed primarily by the depth of water withdrawal from Horne Lake. The 1965 temperature data typify the partial temperature control regime (Fig. 22). Summer temperatures at the lake outlet were only about 1°C higher than at the river mouth, compared to a pre-flow control difference of about 3°C to 5°C (Append. 8). Also, the mean river temperatures in the winter were significantly lower after flow control (1964-1967) than in earlier years (Fig. 21) and most likely reflected increased physical cooling due to lower winter flows.

The 1968 temperature data typify the more extensive temperature control regime where the discharge pattern was further modified to provide lower temperatures for rearing of chum and chinook juveniles in hatchery facilities added in 1968 (Fig. 22). Under artificially crowded conditions, mean summer (May to September) temperatures of less than 11°C were found to lead to increased juvenile growth efficiency and survival, and reduced incidence of disease (Fraser et al., unpublished MS). Therefore, from 1968 onward, large volumes of cool hypolimnial water were used during May/June through October which resulted in reduced summer temperatures at the river mouth by up to 4°C (Fig. 21).

With this regime, a reversal of previous temperature patterns occurred. While winter temperatures were still the same or slightly lower at the river mouth compared to the lake outlet, summer temperatures were now higher at the river mouth (Fig. 22, Append. 8). The difference between air and water temperatures was now larger, so that more heat transfer to the water took place, while cooling by secondary inputs had even less influence than previously since the temperature differential between the river flow and secondary flows was smaller than in earlier years. Diversion of all of Hunt's Creek flow down the flood channel from 1970 onward further reduced the downstream cooling of the Big Qualicum River. Thus, although summer temperatures were significantly reduced, the natural physical processes, such as air-water heat transfer, restricted the potential range of temperature manipulation.

Temperature control was also applied for short-term periods. From May 1 to 5, 1969, due to unseasonably warm weather, the mean water temperature near the river mouth increased from 6.9°C to 9.4°C. On May 6, the water temperature ranged from 6.9°C to 11.1°C. By extrapolation, assuming continued warm air temperatures, it was evident that the optimal temperature range for juvenile salmon (generally 10°C to 16°C, but only 12°C to 14°C for chinook; Brett 1952), would be exceeded within five to ten days thereby endangering hatchery fish. In response to this situation, the intermediate intake valve was closed and only hypolimnial water discharged into the river. The lake outlet and river mouth temperatures were subsequently stabilized at 6.4°C and 9.2°C respectively and the sharp increase in temperature was halted.

The effects of flow control on thermal stratification in Horne Lake and inferences for temperature control in the Big Qualicum River are discussed in Appendix 9.

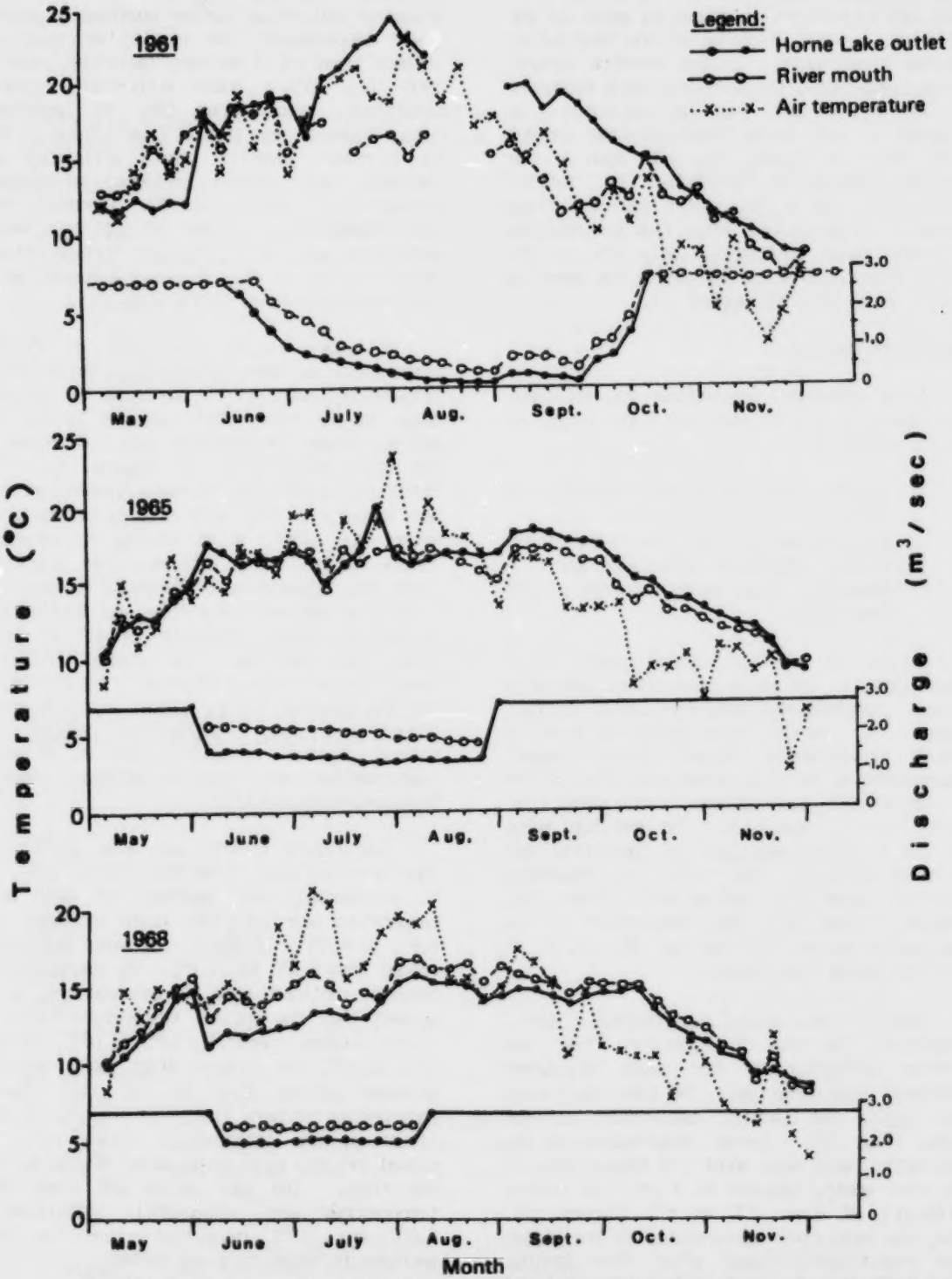


Fig. 22. Water temperature in Big Qualicum River measured at 5-day intervals near Horne Lake outlet and river mouth (camp bridge) during May through November in the pre-flow (1961 data), flow control (1965 data) and temperature control (1968 data) periods. River discharge at the above two sites and air temperature at Cape Lazo (~50 km N.W. of Big Qualicum River, Fig. 33) are also shown.

STREAM IMPROVEMENT

In order to accommodate the 150,000 chum spawners projected for the Big Qualicum River system, given a 50% sex composition and a 1.5 m^2 gravel per female, a minimum of 113,000 m^2 spawning area was required. According to a 1964 survey, over 95% of the river chum utilized a 33,500 m^2 spawning area in a 9 km river reach below hub 124 (Fig. 4). Since the two spawning channels provided an additional 14,800 m^2 spawning area, the required further expansion of the river spawning grounds was about 65,000 m^2.

From 1964 to 1969, the main river bed was upgraded, particularly in the relocation areas (Fig. 4). The stream improvement operations involved the use of a caterpillar tractor (Fig. 23), and included grading, construction of rip-rap and boulder weirs, addition of gravel, river widening, creation of side channels and removal of log jams. Maintenance activities in 1970 and later years included weir repair and construction, opening paths through log jams, digging holding pools, grading and conditioning.

The total spawning area available to chum salmon returning in 1969 was approximately 145,000 m^2 (Table 5) and, excluding contributions from channel No. 2 and the section between hubs 100 and 124 to allow for a direct comparison, represented a 285% increase in spawning area since 1964. This increase is somewhat overestimated since a very detailed 1967 survey of the river from hub 200 to 281 revealed a larger available spawning area than was previously supposed.

The stream improvement program is described more fully in Appendix 10.

CHUM SALMON

Chum salmon in Big Qualicum River

Chum escapement

During 1947 to 1958, prior to project development, annual chum escapement to the Big Qualicum River averaged around 46,000 fish (Table 1). During 1959 to 1972, annual chum escapement to the river averaged 61,000 fish, and to the total system 69,000 fish (range 14,000 to 140,000; Table 6). This accounted for approximately 8% of all chum returning to the Johnstone Strait - Fraser River area. Highest system escapements were recorded from 1966 onward (Table 6), when fish produced in the channels and under the controlled river flow regime started to return.

Chum adult migration timing, river life-span and spawning distribution

Chum salmon arriving into the Big Qualicum River estuary seem to wander off the river mouth at least 48 km along the coast in either direction prior to the up-river migration. This was indicated by tagging experiments in which returning fish were differentially tagged right off the river mouth or along a 48 km straight line on either side of the river mouth. The elapsed time from tagging to river recovery was the same regardless of tagging site.

Chum were observed to hold in the estuary and occasionally in pools below the main fence at hub 290. The time for passage of individual fish from the estuary to the counting fence varied from one-half to 30 days and tended to be less as the season progressed (Walker and Lister 1965).

The overall mean dates (± 1 S.D.) for commencement, 50% completion and total completion of the chum run into Big Qualicum River were October 10 ± 9 days, November 28 ± 4 days and January 2 ± 13 days respectively, although the boundary dates for the run differed by up to a month among years; mean duration of the run was 82 ± 15 days (Fig. 24, Table 7). This period increased significantly after flow control from a mean of 68 days to 87 days (Table 8). Chum moved upstream throughout the day, and in some years large numbers of migrants were observed at dawn and dusk.

Death of spawned out Big Qualicum River chum occurred approximately 13 days after leaving the sea. Walker and Lister (1965) found that the adult chum life-span in Big Qualicum River averaged 13.2 days. Recovery on the spawning grounds of chum tagged in the estuary indicated a similar figure of 12.5 days. During seven years of observation in the present study, the period between peak migration past the fence and peak spawning ground count ranged from 6 to 10 days with a mean of 8.1 days. Redd life was estimated at 6.5 days, based on chum salmon behaviour in channel No. 1. This indicated that chum require approximately five days for upstream movement, site selection and redd construction, then mate during the following 6.5 days. Subsequent die-off occurs within a day or two.

Fig. 23. Stream improvement in Big Qualicum River.

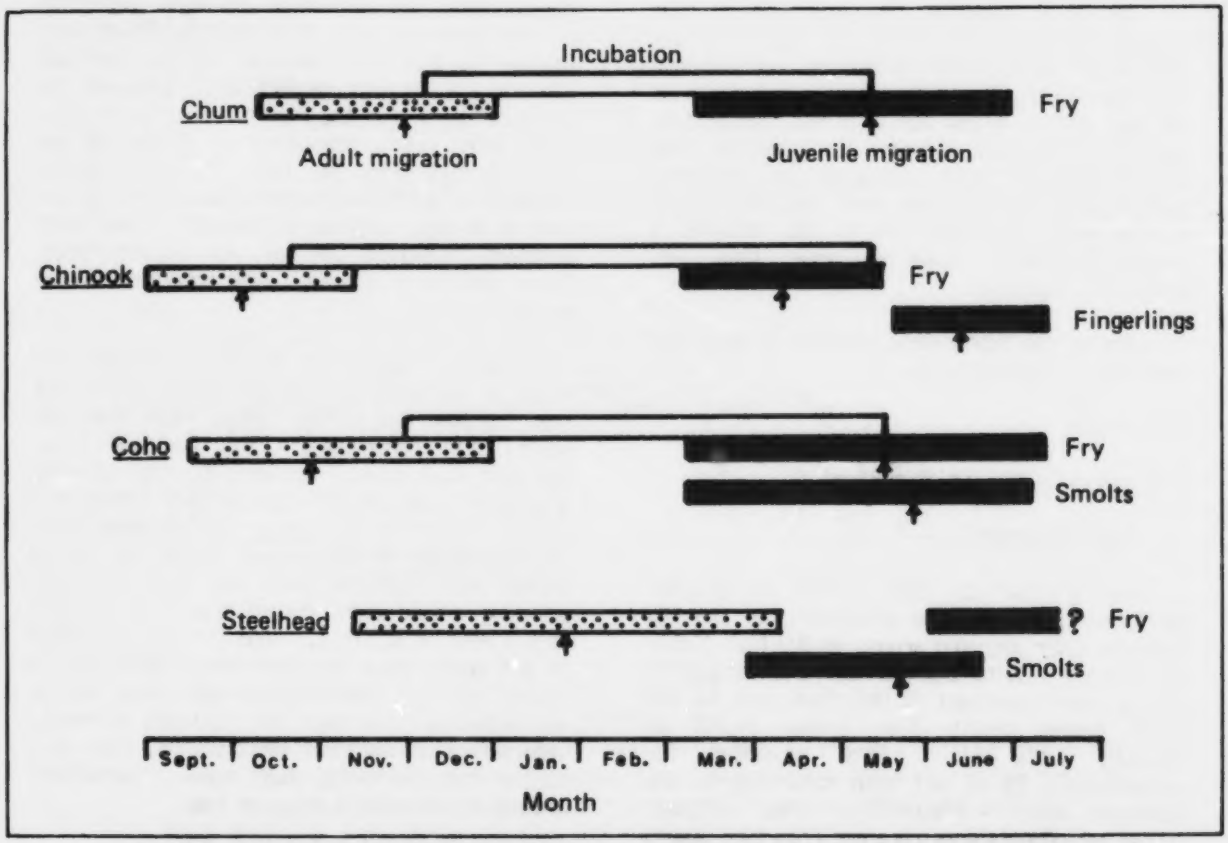


Fig. 24. Adult and juveniie migration and egg incubation timing of chum, chinook, coho and steelhead trout in Big Qualicum River, 1959 – 1972 (arrows indicate mean 50% completion dates of migrations).

Table 6. Annual chum salmon escapement to the Big Qualicum River system, 1959-1972.

Year	River above hub 290	River below hub 290[a]	Spawning channel No. 1	Spawning channel No. 2	Holding pond	System
1959	83,500	15,000	---	---	---	98,500
1960	47,429	12,500	---	---	---	59,929
1961	10,421	3,354	---	---	---	13,775
1962	34,921	12,220	---	---	---	47,141
1963	27,897	7,692	2,092	---	---	37,681
1964	24,739	10,269	1,540	---	---	36,548
1965	12,252	4,385	2,278	---	---	18,915
1966	43,611	7,692	2,540	---	---	53,843
1967	20,604	13,738	607	8,266	0	43,215
1968	102,381	22,246	0	15,757	0	140,384
1969	64,593	19,208	454	16,641	120	101,016
1970	82,930	26,769	0	20,286	2,340	132,325
1971	64,905	24,074	0	17,037	6	106,022
1972	36,079	25,173	0	19,061	200	80,513
Mean	46,876	14,594	---	---	---	69,272

[a] 1959-1960 data based on visual estimates; 1961, 1963-1972 data based on regular spawner counts; 1962 data based on above fence: below fence ratio from 1961 and 1963-1966.

Table 7. Chum adult migration timing past the main fence (hub 290) in Big Qualicum River, 1959-1972.

Year	Start	50%	Finish	Duration (days)
1959	Oct. 13	Nov. 20	Dec. 20	69
1960	Oct. 12	Dec. 1	Dec. 12	62
1961	Oct. 13	Nov. 30	Dec. 21	70
1962	Oct. 12	Nov. 21	Dec. 22	72
1963	Oct. 9	Nov. 26	Dec. 23	76
1964	Oct. 14	Nov. 30	Jan. 21	100
1965	Oct. 21	Nov. 29	Dec. 30	71
1966	Oct. 7	Nov. 28	Jan. 10	96
1967	Oct. 7	Nov. 30	Dec. 31	85
1968	Oct. 6	Nov. 26	Dec. 26	80
1969	Oct. 20	De. 3	Jan. 15	88
1970	Oct. 17	Dec. 6	Jan. 11	87
1971	Sep. 23	Dec. 3	Jan. 24	71
1972	Sep. 19	Nov. 28	Jan. 14	117
Mean	Oct. 10	Nov. 28	Jan. 2	82
± 1 S.D.	± 9	± 4	± 13	±15

Table 8. Comparison of biological parameters for chum salmon in Big Qualicum River before and after flow control, 1959-1972 broods.

Parameter	Before flow control (1959-62 broods) Mean ± 1 S.D.	After flow control (1963-72 broods) Mean ± 1 S.D.	Wilcoxon's U-Statistic[a]	
Adult escapement				
- duration (days)	68 ± 4	87 ± 14	38	**
- 50% completion	Nov. 26 ± 6	Nov. 30 ± 3	27	n.s.
Egg retention (%)	12.3 ± 9.0	4.93 ± 4.86	34	*
Egg incubation				
- duration (days)	151 ± 7	158 ± 10	30	n.s.
- thermal units (°C-days)	1,012 ± 128	851 ± 93	34	*
- mean temperature (°C)	6.7 ± 0.6	5.4 ± 0.6	36.5	*
Fry length	39.3 ± 0.5	38.8 ± 0.6	22.5	n.s.
Fry migration				
- duration (days)	95 ± 16	117 ± 12	35.5	*
- 50% completion	May 3 ± 3	May 15 ± 11	37	**
Egg-to-fry survival (%)	13.7 ± 7.0	29.1 ± 12.0	34	*
Fry-to-adult survival (%)	0.64 ± 0.29	0.66 ± 0.47	22	n.s.

[a] n.s. $p > 0.05$
* $0.05 > p > 0.01$
** $0.01 > p > 0.001$

Considerable variation occurred in the above pattern. For example, mean chum freshwater life-span in spawning channels No. 1 and No. 2 was found to be 12.2 days and 9.5 days respectively and, at least in channel No. 1, it varied from approximately 14 days early in the season to 11 or 12 days during the peak and late spawning periods. Mean redd life in different sections of channel No. 1 ranged from 4.8 days to 8.1 days and was probably at least as variable in different river sections. The 6.5 day overall mean redd life, determined in channel No. 1, is the best available estimate.

Chum spawners were found throughout the river but were most abundant downstream in sections 5 (52% of total chum spawners) and 7 (20% of total; Fig. 25, Table 9). Chum density was highest in the lower river (~ 18,000 fish/km of river length in section 7), decreasing upstream to sections 1 to 3 (~ 1,500 fish/km of river length; Fig. 25, Table 9).

Chum adult age, length and sex composition

Most chum returns to the Big Qualicum River were age 3, 4 or 5 (Table 10). Age 4 fish usually predominated averaging 67.1% over the 14-year period and comprised as much as 92.5% of the 1970 escapement (Table 10). However, age 3 spawners exceeded the older fish in 1962 (84.5% of escapement) and 1965 (51.3% of escapement; Table 10). In both instances of high return of younger fish, escapements of parental stock producing these broods were considerably larger than in the previous year, partly explaining the shift in age composition.

From 1959 to 1972, all chum examined were in the 3, 4, or 5 age groups. However, in 1973 and 1974, age 6 fish accounted for 0.2% and 1.5% of the spawners respectively. Pritchard (1943) noted that fish captured commercially during 1916 to 1942 were commonly 3 to 6 years old with ages 2 and 7 possibly present. The Fraser River chum stocks which are subject to less geographical variation than the total British Columbia fishery are usually 3 to 5 years old with age 2 occurring rarely (Palmer 1972).

The length of 3, 4 and 5-year old chum averaged 555 mm, 592 mm and 607 mm respectively and tended to increase with age (Table 10). However, considerable size variation within an age group rendered age classification by size impossible (Fig. 26). Males and females of equal age had similar lengths (Fig. 26, Append. 14 and 15).

Females comprised on the average 51.3% (range 45.0% - 58.0%) of the river chum spawners above hub 290 (Table 10). This is similar to the female proportion of 50.9% observed for Hooknose Creek chum over a 10-year period (Hunter 1959), and to 50.6% observed for Fraser River chum over an eight-year period (Palmer 1972). Sex composition among Big Qualicum River chum did not vary significantly among age classes (Append. 12).

Dead pitch sampling was also conducted below the fence in some years but was considered unreliable. Males wandered from redd sites in search of new mates or drifted downstream, while females were more rooted to the spawning area. Consequently, the data demonstrated a deficit of males. Sexing of adults as they passed over the flashing at the counting fence was less reliable than sampling of carcasses; however, these data were used in 1965 when no other information was available.

Chum fecundity, egg retention and deposition

In order to estimate the number of eggs deposited in the river, the mean length of females was applied to a regression equation to calculate fecundity.

A number of models for the fecundity-length relationship were tested using the 1959 data (Append. 18). The simple linear model offered as good a fit as any of the more complex equations and, although it accounted for only 50% of the variation observed in the data, was chosen for ease of application and continuity with previous studies. Foerster and Pritchard (1941) and Rounsefell (1957) reported that a linear model adequately described the fecundity-length relationship for mature Pacific salmon.

The above linear relationship was calculated for each of the 1959 to 1972 brood years, except the four years when egg counts were not available (Append. 19). Fecundity estimates for those four years were made using a regression equation involving all the available data:

Fecundity = -3411 + 10.83 (PO-Hyp Length) (r = 0.68)

Annual chum fecundity at the Big Qualicum River averaged 3,069 eggs (range 2,795 - 3,335; Table 10). By comparison, 168 sampled Fraser River chum contained an average of 3,256 eggs over a two-year period (Palmer 1972), while

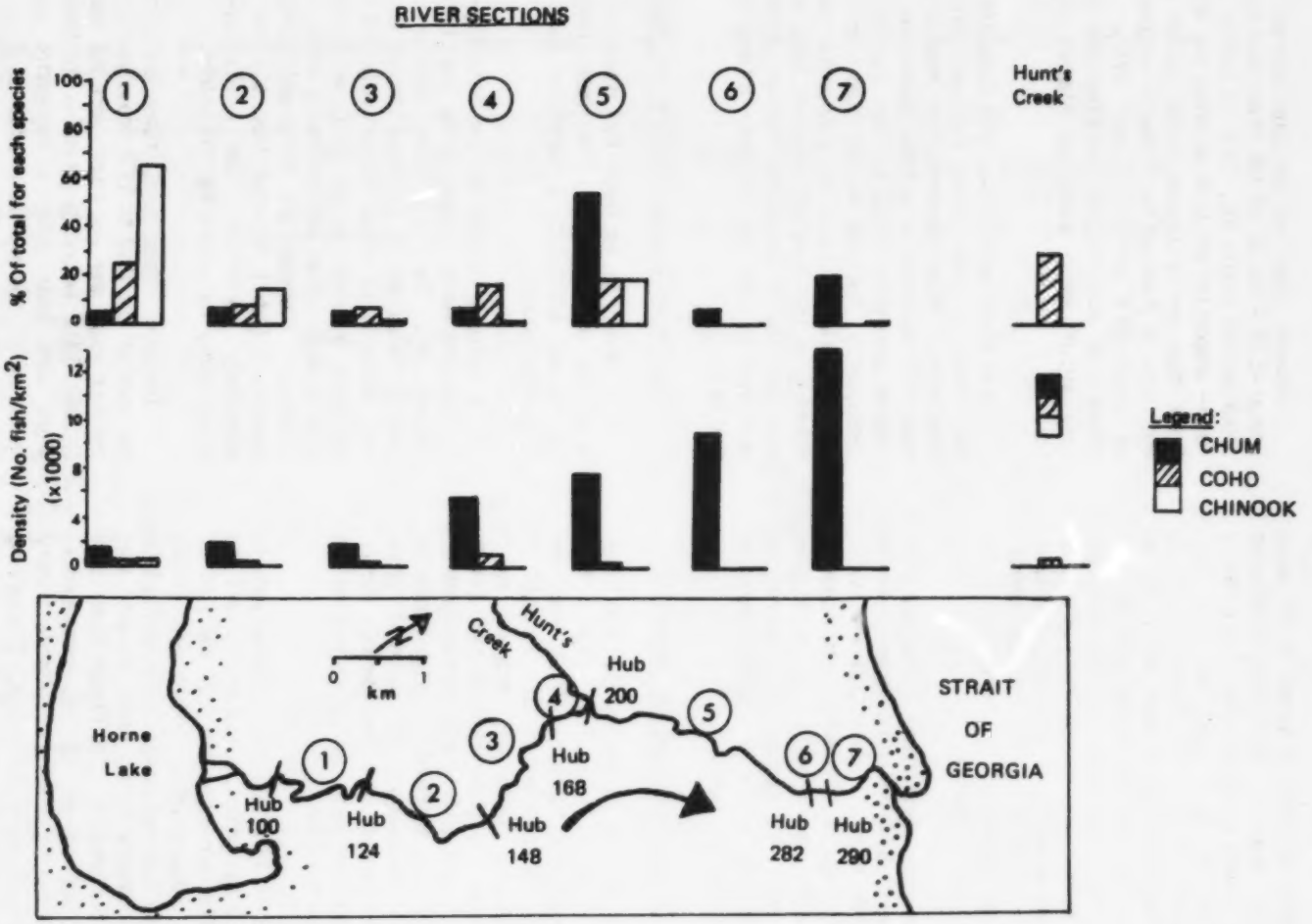


Fig. 25. Distribution and density of chum, coho and chinook spawners in Big Qualicum River system during pre-flow control period; below are shown Big Qualicum River sections 1–7 (circled).

Table 9. Mean annual numbers and densities (fish/km^2) of chum, coho and chinook salmon spawning in the seven sections of Big Qualicum River during 1959-1962.[a]

Section	Total density	Chum			Coho			Chinook		
		No.	% of total	Density	No.	% of total	Density	No.	% of total	Density
1	2,279	2,369	4.3	1,316	801	23.7	445	932	63.8	518
2	2,054	3,466	6.3	1,824	242	7.2	127	196	13.4	103
3	2,041	3,036	5.5	1,898	202	6.0	126	27	1.8	17
4	6,453	3,305	6.0	5,508	556	16.5	927	11	0.8	18
5	7,985	28,626	52.2	7,737	637	18.9	172	282	19.3	76
6	10,890	3,267	6.0	10,890	0	0	0	0	0	0
7	17,968	10,769	19.6	17,948	0	0	0	12	0.8	20
Hunt's Cr.	470	0	0	0	939	27.8	470	0	0	0

[a] Data based on distributions weighted by annual escapements.

Table 10. Chum brood stock characteristics and egg disposition in Big Qualicum River above hub 290, 1959-1972 broods.[a]

Brood year	Age composition (%)			Length (mm) at age				Females (%)	Mean fecundity (eggs/female)	Egg retention (%)	Actual egg deposition (millions)
	3	4	5	3	4	5	All ages				
1959	34.7	64.3	1.0	557	603	581	581	50.7	3,002	25.80	94.30
1960	16.9	83.1	0.0	568	596	—	585	47.1	3,102	8.99	63.06
1961	15.1	80.9	4.0	585	612	622	608	54.7	3,226	7.22	17.06
1962	84.5	15.3	0.2	580	613	664	585	50.3	3,117	7.20	52.43
1963	23.9	76.0	0.1	564	602	586	595	51.4	3,253	6.68	43.53
1964	23.7	75.5	0.8	566	604	633	598	50.8	3,076	2.41	37.73
1965	51.3	45.9	2.8	539	583	586	559	45.0	2,708	1.76	14.67
1966	36.5	62.8	0.7	557	584	596	574	48.7	2,795	1.20	58.64
1967	32.5	67.0	0.5	545	591	595	576	48.8	2,816	1.26	27.96
1968	29.9	69.6	0.5	558	581	625	574	52.1	3,335	2.62	173.20
1969	47.4	49.2	3.4	533	594	604	565	51.8	3,303	0.83	109.60
1970	6.6	92.5	0.9	539	578	603	575	56.5	3,114	6.71	136.10
1971	7.6	81.7	10.7	534	573	590	572	58.0	3,058	10.30	103.30
1972	16.3	75.3	8.4	540	576	605	573	51.6	3,063	15.50	48.18
Mean ± 1 S.D.	30.5±20.6	67.1±19.6	2.4±3.3	555±13	592±13	607±23	580±13	51.3±3.5	3,069±189	7.03±6.87	70.0±46.9

[a] See Append. 11-17 for details.

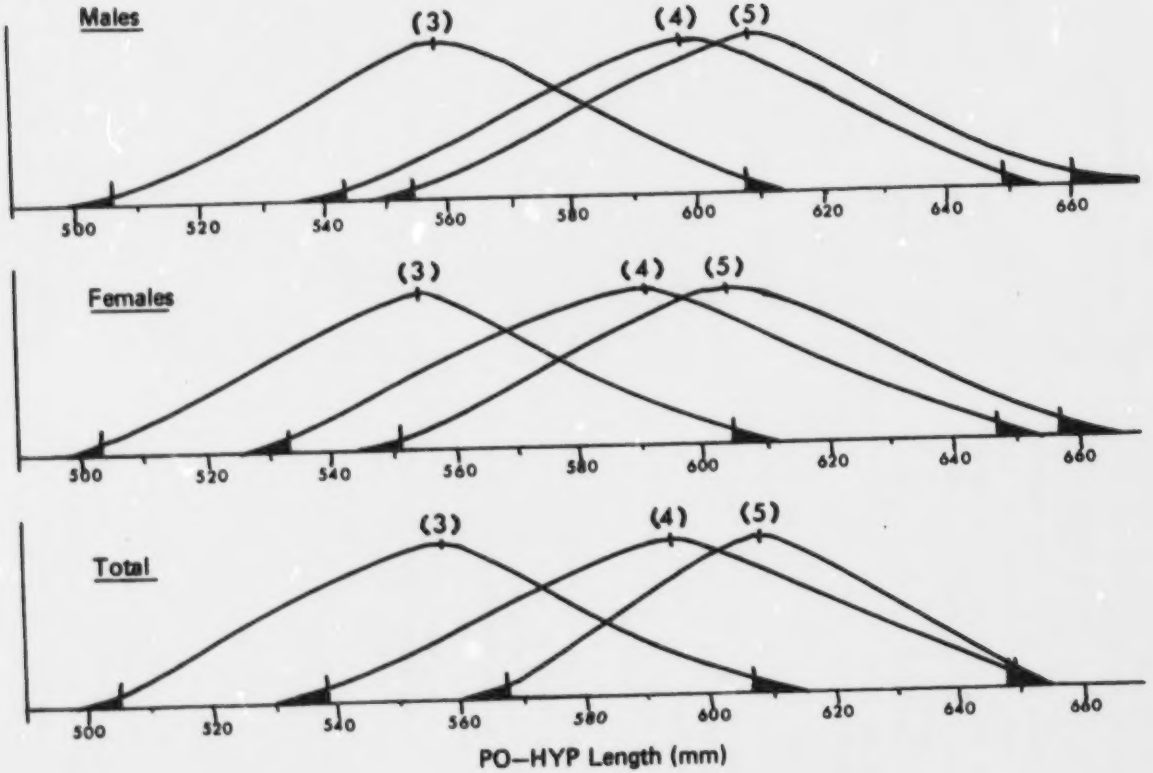


Fig. 26. Confidence limits (95%, unshaded) of the overall mean length of male, female and total chum salmon at ages 3, 4 and 5 (in parenthesis) in Big Qualicum River, 1959 – 1972.

stocks in Hooknose Creek, central B.C., averaged only 2,468 eggs over a 10-year period (Hunter 1959). Individual females may vary considerably in egg content; Bakkala (1970) found that reported counts ranged from 900 to 8,000 eggs per chum female.

Egg retention in chum carcasses on spawning grounds above hub 290 or washed against the fence averaged 7.0% (range 0.8% - 25.8%; Table 10). The high "loss" of 33 million eggs estimated for 1969 indicates the potential impact of incomplete egg deposition. Mean egg retention of Big Qualicum River chum was considerably lower after flow control (4.9%) than in pre-flow control years (12.3%) (Table 8), probably reflecting improved spawning conditions in later years. Increased egg retention in 1971 (10.3%) and 1972 (15.5%) has not been explained.

The actual deposition of eggs by chum spawners was determined by adjusting the total potential egg deposition (derived from fecundity data) for egg retention. The estimated actual egg deposition in the river above hub 290 averaged 70.0 million eggs per year (range 17.1 million - 172.9 million; Table 10).

Intensive sampling data for chum salmon spawning below the main fence at hub 290 were not obtained. In order to estimate egg deposition and subsequent fry production by this sub-population, data on sex composition, fecundity, egg retention and egg-to-fry survival, determined for the above-fence spawners, were applied to total adult numbers in the lower river. The estimated actual egg deposition calculated in this manner averaged 21.8 million eggs per year (range 5.2 million - 43.9 million; Table 11).

Chum egg incubation

The incubation period for each brood of chum eggs was calculated from median spawning date (8 days after peak adult migration past hub 290) until the median date of fry migration past hub 290. The latter date was also the median date of fry emergence because the majority of chum fry migrated immediately upon emerging from the gravel.

Chum eggs incubated from December to May for an average of 156 days (range 144 - 175 days); temperatures during this period averaged 5.8°C (range 4.6°C - 7.7°C); and accumulated thermal units (A.T.U., calculated as one unit for every degree over 0°C each day) averaged 897°C days (range 710 - 1132°C-days) (Fig. 24, Table 12). After flow control, when the mean incubation temperature dropped from 6.7°C to 5.4°C, the A.T.U. requirements declined significantly ($p<0.05$) from 1,012 A.T.U. to 861 A.T.U., so that the length of incubation period showed only a small increase from 151 days to 158 days (Table 8).

Compared to above, chum eggs in Hooknose Creek, B.C. required a much longer incubation period of 211 days (Hunter 1959), largely because this creek is colder than the Big Qualicum River due to its more northern location in B.C. Other factors, such as oxygen concentration, may also affect the development rate of fish eggs (Alderdice et al. 1958).

Chum fry production and migration timing

The annual production of chum fry in the river above hub 290 averaged 14.4 million (range 3.4 million - 32.0 million), and was higher in the post-flow control period (mean 17.3 million) than in the pre-flow control period (mean 7.9 million) (Table 12). Annual chum fry production below hub 290 averaged 4.8 million (range 0.95 million - 10.0 million; Table 11).

Chum fry usually migrated from early March to June or July, with mean (± 1 S.D.) 50% completion of the run occurring on May 11 ± 11 days (Fig. 24, Table 12). Start of migration did not change significantly after flow control, but mid-timing was delayed approximately two weeks (May 3 before flow control; May 15 after flow control; Table 8). The end of the run was similarly delayed after flow control (Append. 21) Duration of downstream run averaged 110 days (range 75-139 days; Table 12) and increased significantly after flow control from 95 to 117 days (Table 8).

Daily movement downstream became significant at dusk. Peak numbers were trapped at midnight or in the early hours of morning and tailed off to near zero at dawn. Traps were emptied regularly between dusk and peak migration, then left until later in the morning, resulting in possible overestimate of post-dawn catches. The above daily pattern corresponds with observations by Neave (1966) that migrating chum fry avoid light.

Table 11. Chum salmon egg deposition and fry production in Big Qualicum River below hub 290, 1959-1972 broods.[a]

Brood year	Actual egg disposition (millions)	Fry production (millions)
1959	16.94	3.22
1960	16.62	0.95
1961	5.49	1.11
1962	17.78	1.74
1963	12.00	4.15
1964	15.66	4.46
1965	5.25	2.52
1966	10.34	3.10
1967	18.64	8.69
1968	37.64	6.17
1969	32.59	10.00
1970	43.94	6.77
1971	38.30	5.17
1972	33.62	9.04
Mean ± 1 S.D.	21.77±12.86	4.79±2.97

[a] Upper river data for sex composition, fecundity, egg retention and egg-to-fry survival were used in these calculations; see Append. 20 for details.

Table 12. Chum egg incubation, fry enumeration and sampling, and egg-to-fry survival in Big Qualicum River above hub 290, 1959-1972 broods.[a]

Brood year	Mean incubation temperature (°C)	Incubation period (days)	Accumulated thermal units (°C-days)	Migration timing		Migrant fry			No. fry[b] (millions)	Eggs-to-fry survival (%)
				50% completion	Duration (days)	Mean length (mm)	Mean weight[c] (mg)	Condition coefficient (mg/mm^3)		
1959	6.7	160	1072	May 6	75	-	-	-	17.9	19.0
1960	7.7	147	1132	May 5	92	38.9	-	-	3.6	5.7
1961	5.8	144	835	May 1	113	39.9	-	-	3.4	20.2
1962	6.6	153	1010	May 1	101	39.2	400	0.66	5.1	9.8
1963	6.8	154	1047	May 6	117	37.2	380	0.75	15.0	34.6
1964	5.4	161	869	May 18	101	39.2	370	0.61	10.8	28.5
1965	5.8	151	876	May 7	108	39.4	350	0.57	7.1	48.1
1966	5.3	154	816	May 9	111	39.0	350	0.59	17.6	30.0
1967	5.6	156	874	May 12	116	38.9	350	0.60	12.9	46.9
1968	4.6	174	800	May 27	117	38.8	350	0.59	28.1	16.4
1969	5.7	146	832	May 6	139	38.9	350	0.59	32.0	30.7
1970	5.3	175	928	June 7	134	39.2	360	0.63	20.9	15.6
1971	4.7	162	761	May 21	115	38.2	330	0.59	14.0	13.7
1972	4.8	148	710	May 3	107	38.9	350	0.59	12.9	26.8
Mean ±1 S.D.	5.8±0.9	156±10	897±124	May11±11	110±16	38.9±0.6	358±19	0.62±0.05	14.4±8.6	24.7±12.8

[a] See Append. 21-23 for details.
[b] Number of fry produced above hub 290 (Append. 22) adjusted for losses (Append. 23).
[c] Fry weights were measured regularly from 1962 onward.

Chum fry size

Daily sample means of chum fry lengths and weights were extrapolated to daily migration totals to estimate the annual means. Migrant chum fry averaged 38.9 mm (range 37.2 mm - 39.9 mm) and 358 mg (range 330 mg - 400 mg); their condition coefficient averaged 0.62 (range 0.57 - 0.75) (Table 12). No significant difference in fry size was observed before and after flow control (Table 8). A few exceptionally large fry up to 60 mm in length were observed during the latter half of the migratory periods but they were generally too scarce to influence the daily means which showed no tendency toward larger size as the season progressed (Fig. 27).

Chum egg-to-fry survival

The annual egg-to-fry survival of Big Qualicum River chum, based on actual egg deposition and fry production numbers, averaged 24.7% (range 5.7% - 48.1%; Table 12). These survival rates reflect the success of spawn placement, fertilization efficiency and survival during incubation, but not egg retention. Survival more than doubled after flow control from an average of 13.7% to 29.1% (Table 8).

Chum salmon in spawning channel No. 1

Chum escapement, migration timing and spawning distribution

During 1963 to 1969, up to 2,540 chum spawned annually in channel No. 1 (Table 13). In addition, stray coho were recorded there during 1963 to 1966 and several chinook were observed in the top channel section in 1964 (Table 13).

Chum migrated into the channel over a period of approximately one month, from mid-November to mid-December (Table 14). The 50% completion date ranged from November 28 to December 2 and fell within one week of the mid-point for system migration each year (Fig. 28, Table 14). Duration of the run to channel No. 1 was very constricted (mean 27 days) compared to that in the river (mean 86 days) (Table 15). This difference reflected the management decisions concerning the timing and number of chum permitted to enter the channel.

Chum generally spawned throughout the channel length except for areas utilized for transplanted pink eggs. The 1966 spawner distribution study in channel No. 1 showed that the highest seasonal and instantaneous chum densities (0.9 m^2 and 1.7 m^2 per female respectively) were found in grid 3 of the channel (Table 16; Giles MS 1967). This portion of the channel was shallowest (41 cm) and had the highest mean velocity (65 cm/sec) of all the test grids except grid 1 (that grid may have been avoided due to local traffic on a bridge crossing the channel at that point). In general, the preferred spawning areas selected by 68% of the early spawners, had water flows in excess of 60 cm/sec and a depth of 45 cm or less, a combination that was rare in channel No. 1.

Chum adult age, length and sex composition

The mean age and length of channel No. 1 chum spawners, measured in 1964 and 1965 (Table 17) were similar to values reported for the river chum (Table 15).

Females comprised on the average 54.0% (range 46.8% - 61.3%) of channel No. 1 chum spawners (Table 17), and were 5% to 10% higher in proportion compared to the river spawners in 1953, 1966 and 1969 (Table 10).

Chum fecundity, egg retention and deposition

Fecundity of chum females in spawning channel No. 1 was estimated by applying the annual length-fecundity regression equations for main river chum to length data for channel No. 1 spawners. In 1967, when length samples were not taken in the channel, the average length of main river chum females was used. Mean fecundity of chum in channel No. 1 was 3,007 eggs (range 2,675 - 3,296 eggs; Table 17).

Egg retention was measured for all chum broods utilizing channel No. 1, except in 1967 (Table 17), and was found to be significantly higher compared to the river chum (18.1% vs 2.6%; Table 15). Egg retention in channel No. 1 was monitored closely in 1966. Retention measured approximately 4.5% until December 1, then peaked to 22.2% by December 13 (Table 18). Dead, unspawned females increased dramatically during the spawing season and accounted for 83% of the total egg retention recorded in 1966, while partially spawned females accounted for the remainder (Table 18). No evidence of disease or environmental problems was found (all eggs were loose within the body cavity). No correlation was evident between egg retention and the number

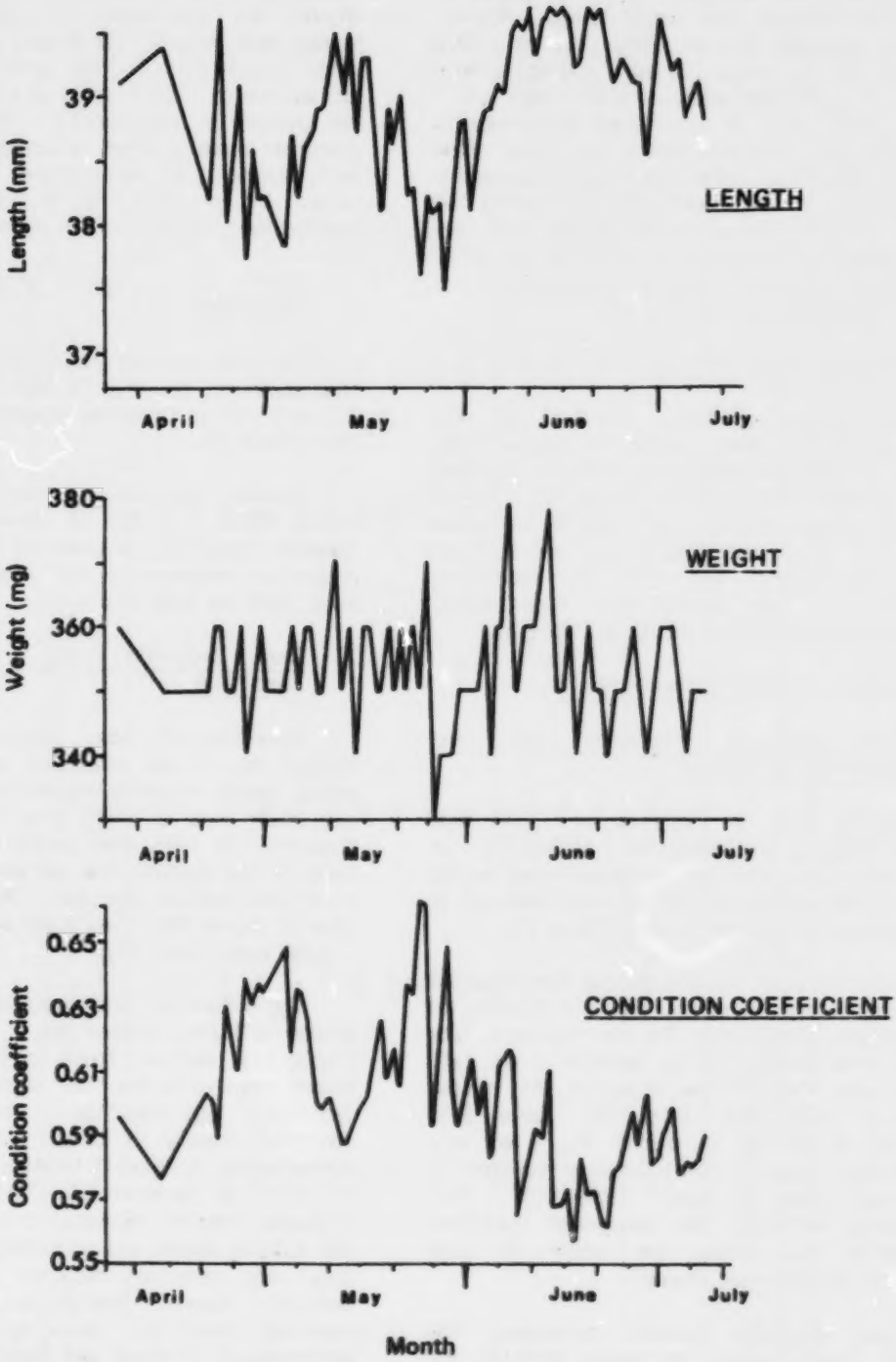


Fig. 27. Mean daily length, weight and condition coefficient of chum fry migrating in Big Qualicum River, 1970 brood.

Table 13. Numbers of adult salmon by species spawning in Channel No. 1, 1963-1969.

Year	Species			
	Chum	Coho	Chinook	Pink
1963	2,092	57	0	5.3 million eggs transplanted
1964	1,540	98	70	6.3 million eggs transplanted
1965	2,278	100	0	5
1966	2,540	66	0	0
1967	607	0	0	0
1968	0	0	0	217
1969	454	0	0	0

Table 14. Chum adult migration timing into spawning channel No. 1, 1963-1967 and 1969.

Year	No. fish	Migration timing				Date of 50% main river migration
		Start	50%	Finish	Duration (days)	
1963	2,092	Nov. 11	Dec. 1	Dec. 10	29	Nov. 26
1964	1,540	Nov. 10	Nov. 30	Dec. 26	46	Nov. 30
1965	2,278	Nov. 17	Nov. 28	Dec. 20	33	Nov. 29
1966	2,540	Nov. 17	Dec. 1	Dec. 6	19	Nov. 28
1967	607	no daily counts available				
1969	454	Nov. 22	Dec. 2	Dec. 2	10	Dec. 3
Mean ± 1 S.D.	-	Nov. 15 ±5	Dec. 1 ±2	Dec. 13 ±10	27±14	Nov. 23 ±12

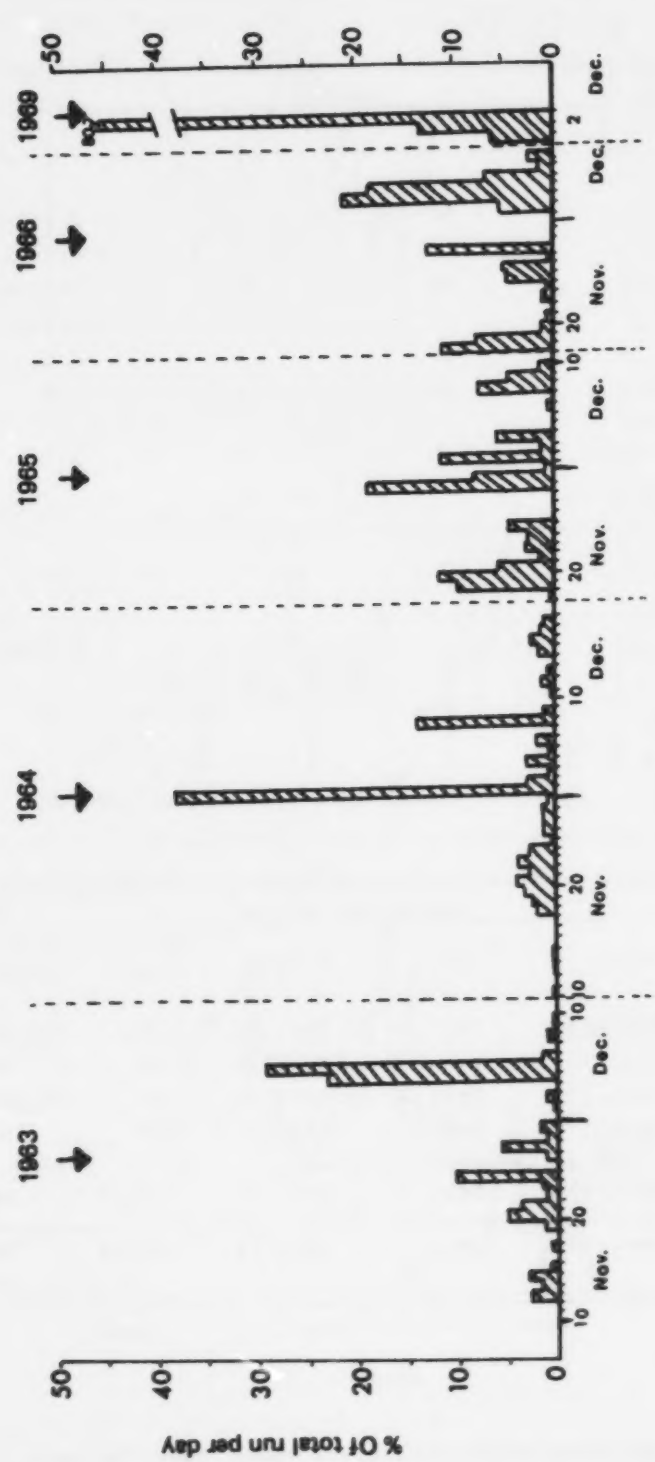


Fig. 28. Annual migration timing of chum adults into spawning channel No.1, 1963 – 1966 and 1969 (arrows indicate 50% completion of river adult migration).

Table 15. Comparision of biological parameters for chum salmon in Big Qualicum River and spawning channel No. 1, 1963-1969 broods.

Parameter	Broods compared	River mean ± 1 S.D.	Channel No. 1 mean ± 1 S.D.	Wilcoxon's U-Statistic[a]	
Adult escapement					
- duration (days)	1963-66,69	86 ± 12	27 ± 14	25	**
- 50% completion	1963-66,69	Nov. 29 ± 3	Nov. 30 ± 2	17	n.s.
Adult sampling				---	
- age (years)	1964,65	3.65 ± 0.18	3.66 ± 0.17	15	n.s.
- length (mm)	1963-66,69	578 ± 18	582 ± 17	18	n.s.
- females (%)	1963-66,69	49.5 ± 2.8	54.0 ± 6.0	23	*
- egg retention (%)	1963-66,69	2.6 ± 2.4	18.1 ± 12.4		
Incubation					
- duration (days)	1963-66	155 ± 4	157 ± 7	8.5	n.s.
- thermal units (°C-days)	1963-66	902 ± 100	892 ± 47	8.0	n.s.
Fry sampling					
- length (mm)	1963-67	38.7 ± 0.9	39.0 ± 0.5	12.5	n.s.
- weight (mg)	1963-67	360 ± 14	360 ± 29	15.5	n.s.
- condition (mg/mm^3)	1963-67	0.621 ± 0.071	0.605 ± 0.033	13.5	n.s.
Fry migration					
- duration	1963-67	111 ± 17	58 ± 13	25	**
- 50% completion	1963-67	May 10 ± 5	May 14 ± 7	16.5	n.s.
Egg-to-fry survival (%)	1963-67,69	36.4 ± 8.7	32.9 ± 30.1	21	n.s.

[a] n.s. $p > 0.05$
* $0.05 > p > 0.01$
** $p < 0.01$

Table 16. Water velocity and depth, and chum female spawning density at 13 stations in channel No. 1 during 1966[a].

Grid No.	Mean cross-sectional Velocity (cm/sec)	Mean cross-sectional Depth (cm)	No. females observed	Spawning density Mean seasonal (m^2/female)	Spawning density Max. instantaneous (m^2/female)
1	73	37	11	1.8	-
2	50	46	13	1.6	2.9
3	65	41	22	0.9	1.7
4	48	46	8	2.5	3.3
5	51	45	10	2.0	2.2
6	52	45	5	4.0	4.0
7	51	46	3	6.7	6.7
8	52	45	10	2.0	2.0
9	-	-	10	2.0	2.9
10	51	44	10	2.0	5.0
11	45	45	0	-	-
12	47	49	0	-	-
13	-	-	0	-	-
Mean	53	45	-	-	-

[a] See Fig. 17 for location of spawning distribution grids.

Table 17. Chum brood stock characteristics and egg disposition in spawning channel No. 1, 1963-1969 broods.[a]

Brood year	Age composition (%)			Length (mm) at age				Females (%)	Mean fecundity (eggs/female)	Egg retention (%)	Actual egg deposition (millions)
	3	4	5	3	4	5	All ages				
1963	-	-	-	-	-	-	596	61.3	3,253	10.1	3.75
1964	23.3	75.6	1.2	569	608	606	602	49.2	3,130	33.3	1.58
1965	46.8	52.8	0.4	540	585	591	563	46.8	2,675	1.9	2.80
1966	-	-	-	-	-	-	580	54.5	2,870	19.7	3.19
1967	-	-	-	-	-	-	-	-	2,816	-	0.68
1969	-	-	-	-	-	-	569	58.1	3,296	25.7	0.65
Mean ± 1 S.D.	35.1±16.6	64.2±16.1	0.8±0.6	555±21	597±16	599±11	582±17	54.0±6.0	3,007±255	18.1±12.4	2.11±1.33

[a] See Append. 24-28 for details.

Table 18. Chum salmon egg retention in spawning channel No. 1, 1966 brood.

Date	Total egg retention (%)	Egg retention due to completely unspawned females (%)	Approx. No. active females in channel No. 1
Up to Dec. 1	4.5	0	565
Dec. 5-7	12.7	9.4	1066
Dec. 9-12	17.7	14.6	831
Dec. 13	22.2	20.0	735
Dec. 16 to end	20.9	15.4	435
Seasonal mean	17.6	14.6	---

of active females in the channel determined by substraction of dead pitch recovery from immigrant counts (Table 18). The only difference noted between spawned and unspawned females was a slightly but significantly ($p < 0.05$) larger size of unspawned females (average length ± 1 S.D. of 450 spawned and partially spawned female carcasses was 579 ± 30 mm compared to an average of 585 ± 26 mm for 71 unspawned females).

The estimated actual egg deposition in channel No. 1 averaged 2.11 million eggs per year (range 0.65 million - 3.75 million; Table 17). From 1963 to 1969, channel No. 1 received approximately 3% of all chum eggs deposited in the Big Qualicum River system.

Chum egg incubation

The chum incubation period in channel No. 1, calculated as for the main river population, averaged 157 days (range 151 - 167 days); and the A.T.U.'s averaged 892°C days (range 851 - 952 °C-days) (Table 19). Neither of these parameters varied significantly between channel and the river (Table 15). Incubation temperatures in channel No. 1 were within 1°C of those in the Big Qualicum River measured at the camp bridge (Tables 12 and 19).

Chum fry production and migration timing

Maximum chum fry production in spawning channel No. 1 occurred during the first year of operation when the migrant population was estimated at 1.78 million (Table 19). Subsequent production levels were much lower and fell to virtually zero for the 1969 brood year when 264 females spawned. In 1969, spawning channel No. 1 was converted into a rearing facility.

The mid-point of fry migration from channel No. 1 occurred in May (Fig. 29, Table 19), and was within a few days of the river mid-timing each year (Table 15). However, mean duration of the downstream run in channel No. 1 (58 days) was much shorter than that in the river (111 days) (Table 15) and reflected a condensed spawning period in channel No. 1 compared to the river.

Chum fry size

Lengths, weights and condition coefficients for channel No. 1 chum fry averaged 39.0 mm, 360 mg and 0.605 respectively (Table 19), and were similar to values for the river fry for the same time period (Table 15).

Chum egg-to-fry survival

The annual egg-to-fry survival of chum in channel No. 1 averaged 32.9% but was highly inconsistent (range 0% - 82.5%; Table 19). Fry survivals in the main river for the same brood years averaged 36.4% (range 28.5% - 48.1%) and did not differ significantly from channel survivals (Table 15).

Chum salmon in spawning channel No. 2

Chum escapements, migration timing and spawning distribution

During 1967 to 1972, up to 20,286 chum spawned annually in channel No. 2 (Table 20).

Chum migrated into the channel over a period of one to three weeks, from November to December (Table 20). The 50% completion dates ranged from November 19 to December 3 and fell within one week of the mid-point for system migration each year (Fig. 30, Table 20). As in channel No. 1, duration of the run to channel No. 2 was very constricted (mean 18 days) compared to that in the river (mean 88 days) (Table 21). This difference reflected the management decisions concerning the timing and number of chum permitted to enter the channel.

Distribution of chum spawners in channel No. 2 was monitored for all broods except the first. In 1968, twice as many fish preferred the upper sections of the channel compared to the lower sections (Fig. 31). During the 1969 spawning season a fence was erected between sections 5 and 6 to permit control over the number of fish migrating to the upper end of the channel. In 1970, spawning dividers which could be sealed to block later migrants were erected at four locations (Fig. 31) to prevent density-related spawning losses. This resulted in a much more homogeneous distribution of spawners although some accumulation was noted immediately below the barriers (Fig. 31).

Behavioral studies in 1967 on the distribution of chum spawners in channel No. 2, where concrete building blocks provided visual isolation and variable current patterns, showed no difference in spawner distribution (judged by redd location) in areas with and without blocks.

Chum adult age, length and sex composition

As in the case of spawning channel No. 1, channel No. 2 chum spawners appeared to be a

Table 19. Chum egg incubation, fry enumeration and sampling, and egg-to-fry survival in spawning channel No. 1, 1963-1969 broods.[a]

Brood year	Mean incubation temperature (°C)	Incubation period (days)	Accumulated thermal units (°C-days)	Migration timing		Migrant fry			No. fry (millions)	Eggs-to-fry survival (%)
				50% completion	Duration (days)	Mean length (mm)	Mean weight (mg)	Condition coefficient (mg/mm^3)		
1963	6.0	151	906	May 8	67	38.4	350	0.618	1.78	47.6
1964	5.7	167	952	May22	55	39.8	410	0.650	0.10	6.6
1965	5.6	152	851	May 6	70	38.9	360	0.612	0.69	24.8
1966	5.5	156	858	May13	38	39.0	340	0.573	1.14	35.8
1967	—	—	—	May19	58	39.0	340	0.573	0.56	82.5
1969	—	—	—	—	—	—	—	—	0	0
Mean ± 1 S.D.	5.7±0.2	157±7	892±47	May14±7	58±13	39.0±0.5	360±29	0.605±0.035	0.71±0.67	32.9±30.1

[a] See Append. 29 for details.

Table 20. Number of adult chum and their migation timing into spawning channel No. 2, 1967-1972.

Year	No. fish	Migration timing			Duration (days)	Date of 50% main river migration
		Start	50%	Finish		
1967	8,266	Nov. 18	Nov. 30	Dec. 10	22	Nov. 30
1968	15,757	Nov. 12	Nov. 19	Nov. 20	8	Nov. 26
1969	16,641	Nov. 14	Dec. 3	Dec. 8	25	Dec. 3
1970	20,286	Nov. 23	Dec. 1	Dec. 6	13	Dec. 6
1971	17,037	Nov. 20	Nov. 28	Dec. 5	15	Dec. 3
1972	19,061	Nov. 23	Dec. 1	Dec. 14	22	Nov. 28
Mean ± 1 S.D.	---	Nov. 18 ±5	Nov. 29 ±5	Dec. 6 ±8	18±7	Dec. 1 ±4

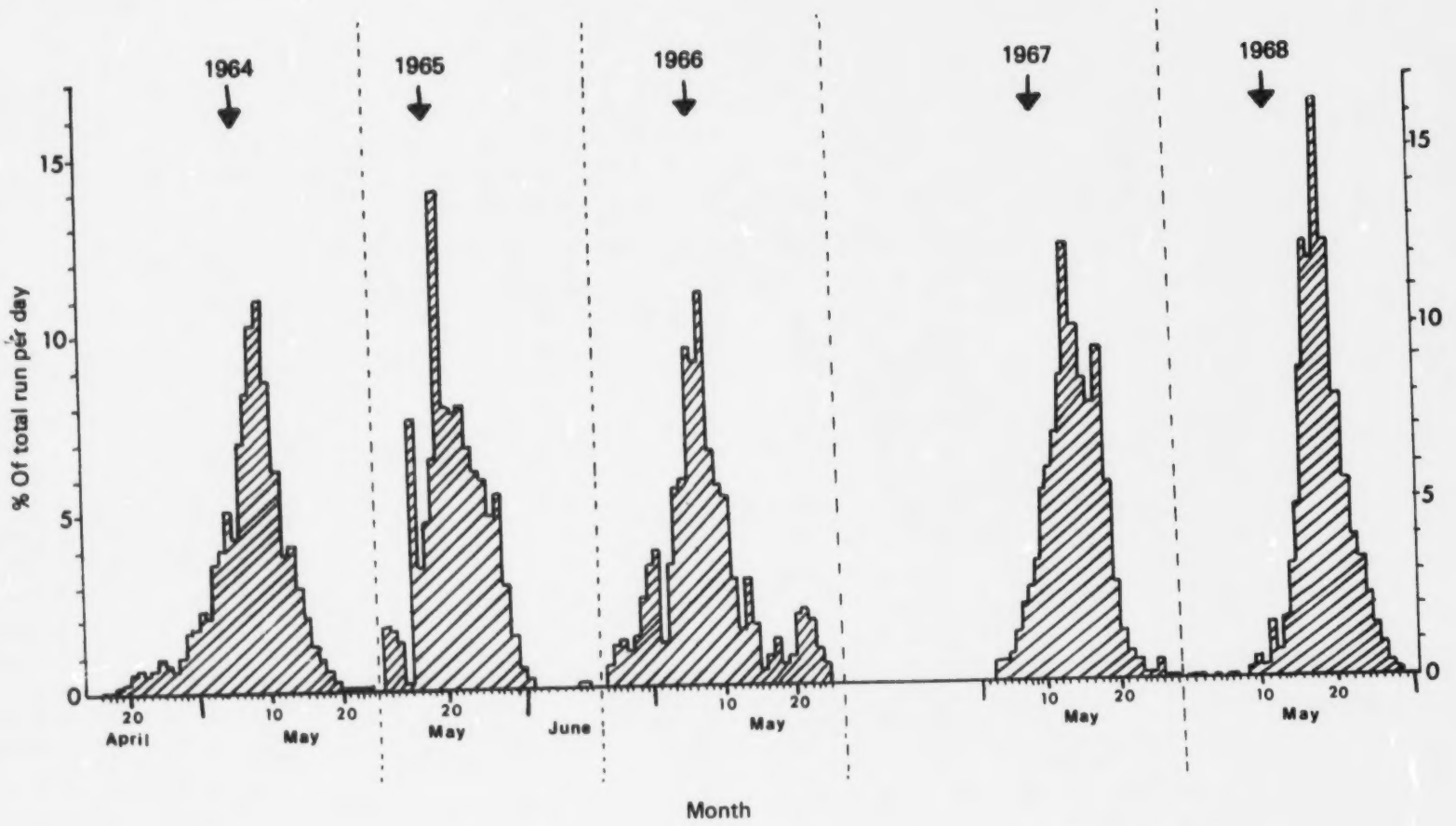


Fig. 29. Annual migration timing of chum fry from spawning channel No.1, 1964 – 1968 (arrows indicate 50% completion of river downstream migration).

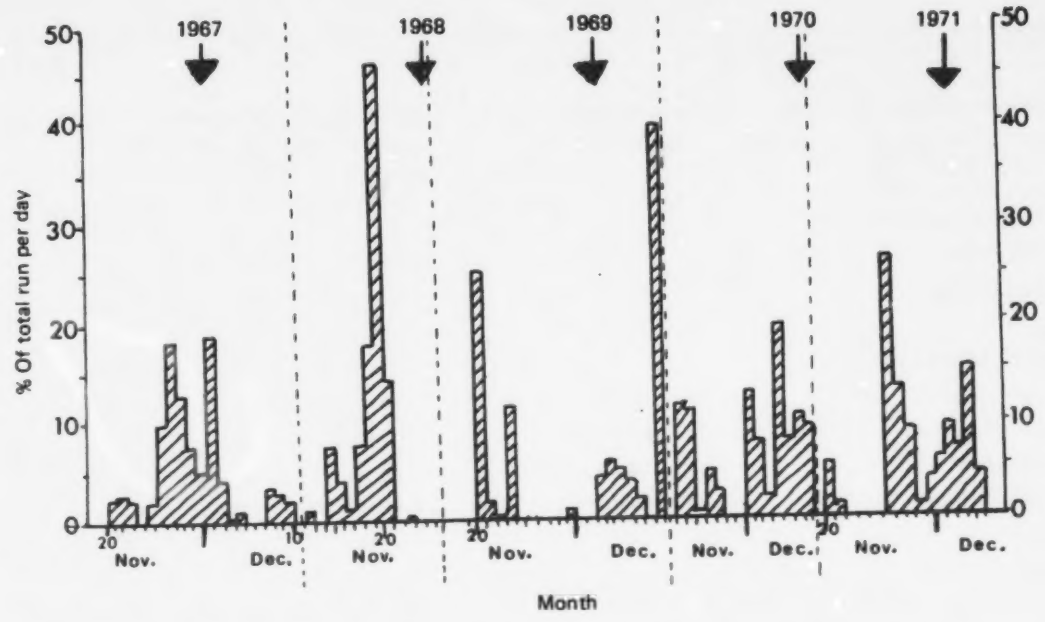


Fig. 30. Annual migration timing of chum adults into spawning channel No.2, 1967 – 1971 (arrows indicate 50% completion of river adult migration).

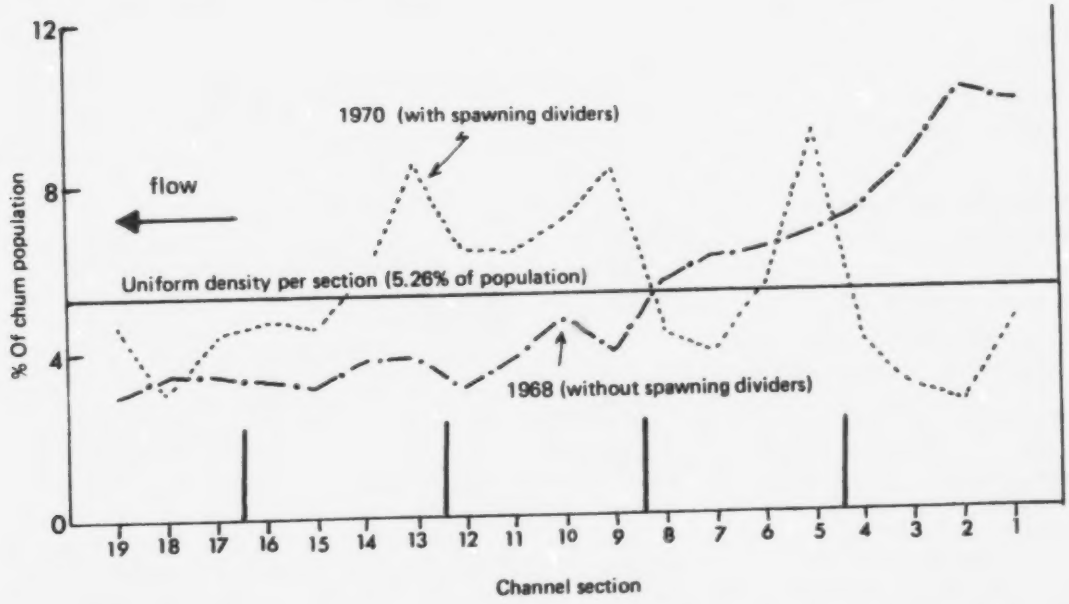


Fig. 31. Distribution of chum spawners in spawning channel No.2 with (1970) and without (1968) spawning dividers .

Table 21. Comparison of biological parameters for chum salmon in Big Qualicum River and spawning channel No. 2, 1967-1972 broods.

Parameter	River mean ± 1 S.D.	Channel No. 2 mean ± 1 S.D.	Wilcoxon's U-Statistic[a]
Adult escapement			
- duration (days)	88 ± 16	18 ± 7	36 **
- 50% completion	Dec. 1 ± 4	Nov. 29 ± 5	22 n.s.
Adult sampling			
- age (years)	3.81 ± 0.18	3.79 ± 0.18	18 n.s.
- length (mm)	573 ± 4	571 ± 9	19 n.s.
- females (%)	53.1 ± 3.4	53.8 ± 5.7	22 n.s.
- egg retention (%)	6.2 ± 5.8	5.9 ± 4.1	19 n.s.
Incubation			
- duration (days)	160 ± 12	164 ± 11	21 n.s.
- thermal units (°C-days)	818 ± 78	853 ± 55	24 n.s.
Fry sampling			
- length (mm)	38.8 ± 0.3	38.7 ± 0.4	21.5 n.s.
- weight (mg)	348 ± 10	347 ± 10	20 n.s.
- condition (mg/mm^3)	0.599 ± 0.016	0.596 ± 0.006	22.5 n.s.
Fry migration			
- duration (days)	121 ± 12	74 ± 18	36 **
- 50% completion	May 18 ± 13	May 19 ± 9	19 n.s.
Egg-to-fry survival (%)	24.9 ± 12.7	74.5 ± 10.3	36 **

[a] n.s. $p > 0.05$
** $p < 0.01$

representative sample of the Big Qualicum River system population. No consistent bias in age or length was found, and annual trends were generally similar in the river and channel populations (Tables 21 and 22).

Sex ratios were not consistent between the channel and river spawners. In 1967 and 1972, the proportion of females was considerably higher in channel No. 2 (55.5% and 60.0%) compared to the river (48.8% and 51.6%), while in 1968 it was higher in the river (52.1%) compared to the channel (43.6%) (Tables 10 and 22). The predominance of males in channel No. 2 in 1968 probably reflected the fact that males predominate among the early returning chum in Big Qualicum River (DFO, Big Qualicum River file No. 5903-85-(5-b); channel No. 2 was completely stocked by November 20, 1968, while the mid-point for total escapement that year was not until November 27. In 1970, 855 males were selectively removed from channel No. 2, increasing the sex ratio in the channel to 58.7% females.

Chum fecundity, egg retention and deposition

Fecundity of chum females in spawning channel No. 2 was estimated by applying the annual length - fecundity regression equations for main river chum to length data for channel No. 2 spawners. Mean fecundity of chum in channel No. 2 was 3,094 eggs (range 2,870 - 3,335 eggs; Table 22).

Egg retention averaged 5.9% and was not significantly different from that of the river spawners (Table 21). Egg retention in channel No. 2 increased significantly from 1967 to 1972 (Table 22).

The estimated actual egg deposition in channel No. 2 averaged 25.6 million eggs per year (range 13.0 million - 33.6 million; Table 22). From 1967 to 1972, channel No. 2 received approximately 16% of all chum eggs deposited in the Big Qualicum River system.

Chum egg incubation

The incubation period in channel No. 2, calculated as for the main river population, averaged 164 days (range 146-175 days); the A.T.U.'s averaged 853°C-days (range 770 - 907°C-days) (Table 23). Neither of these parameters varied significantly between the channel and the river (Table 21). Incubation temperatures in channel No. 2 were within 1°C of those in the Big Qualicum River measured at the camp bridge (Tables 12 and 23).

Chum fry production and migration timing

Chum fry production in channel No. 2 averaged 18.4 million fry (range 11.7 million - 22.5 million; Table 23). Downstream fry totals were significantly different from production totals for the 1967 to 1969 and 1972 broods (Append. 22 and 23). In the 1967 to 1969 broods, recorded "losses" consisted of fry taken for chum rearing experiments (Fraser et al. 1978). During the 1973 downstream run, failure of a fyke net in channel No. 2 resulted in 0.8 million fry mortalities.

The mid-point of fry migration from channel No. 2 occurred in May (Fig. 32, Table 23) and was generally within one week of the river mid-timing each year (Table 21). However, in 1973, the median timing of channel No. 2 fry was delayed by about two weeks compared to river fry (Tables 12 and 23). This is difficult to explain since mean incubation temperatures were higher in the channel (5.6°C) than the river (4.8°C), and only three days separated peak adult counts in the two systems (Table 20).

As in spawning channel No. 1, mean duration of the downstream run in channel No. 2 (74 days) was much shorter than that in the river (121 days) (Table 21) and reflected a condensed spawning period in channel No. 2 compared to the river.

Chum fry size and swimming endurance

Lengths, weights and condition coefficients for channel No. 2 chum fry averaged 38.7 mm, 347 mg and 0.596 respectively (Table 23), and were similar to values for the river fry for the same time period (Table 21).

Swim tunnel tests were carried out on the 1970 brood chum river fry and channel No. 2 fry in order to detect any differences in stamina between the two groups. Variables affecting stamina test results included fish size, water temperature, oxygen levels, sampling technique, sample size, starvation, time period before testing, and recovery period between repeat tests (Thomas et al. 1964). In general, river fry tended to outlast channel fry but the differences were not significant (Table 24). Considering the large number of fry tested (see methods) it was notable that the coefficients of variation at

Table 22. Chum brood stock characteristics and egg deposition in spawning channel No. 2, 1967-1972 broods.[a]

Brood year	Age composition (%)			Length (mm) at age				Females (%)	Mean fecundity (eggs/female)	Egg retention (%)	Actual egg deposition (millions)
	3	4	5	3	4	5	All ages				
1967	22.8	76.0	1.2	549	591	596	581	55.5	2,870	1.55	12.97
1968	26.1	73.9	0	561	578	-	573	43.6	3,335	3.96	22.00
1969	57.2	39.6	3.2	532	586	604	557	52.5	3,205	2.51	27.30
1970	7.6	91.8	0.6	544	578	624	576	56.3	3,114	9.09	33.71
1971	18.7	76.1	5.2	533	568	581	562	54.2	2,955	12.10	23.98
1972	10.7	83.2	6.1	541	576	601	574	60.8	3,082	6.06	33.56
Mean ± 1 S.D.	23.9±17.8	73.4±17.8	2.7±2.5	543±11	580±8	601±16	571±9	53.8±5.7	3,094±168	5.88±4.07	25.59±7.84

[a] See Append. 30-34 for details.

Table 23. Chum egg incubation, fry enumeration and sampling, and egg-to-fry survival in spawning channel No. 2, 1967-1972 broods.[a]

Brood year	Mean incubation temperature (°C)	Incubation period (days)	Accumulated thermal units (°C-days)	Migration timing		Migrant fry			No. fry (millions)	Eggs-to-fry survival (%)
				50% completion	Duration (days)	Mean length (mm)	Mean weight (mg)	Condition coefficient (mg/mm^3)		
1967	5.6	158	885	May 14	75	39.3	360	0.585	11.7	90.1
1968	4.4	175	770	May 19	48	38.7	350	0.601	17.6	80.1
1969	5.7	146	832	May 5	95	39.0	350	0.599	20.9	76.4
1970	5.2	174	905	May 31	91	38.4	350	0.596	20.4	60.6
1971	4.8	170	816	May 24	69	38.5	340	0.594	17.5	72.9
1972	5.6	162	907	May 18	64	38.2	330	0.599	22.5	67.0
Mean ± 1 S.D.	5.2±0.5	164±11	853±55	May 19±9	74±18	38.7±0.4	350±10	0.596±0.006	18.4±3.8	74.5±10.3

[a] See Append. 35 for details.

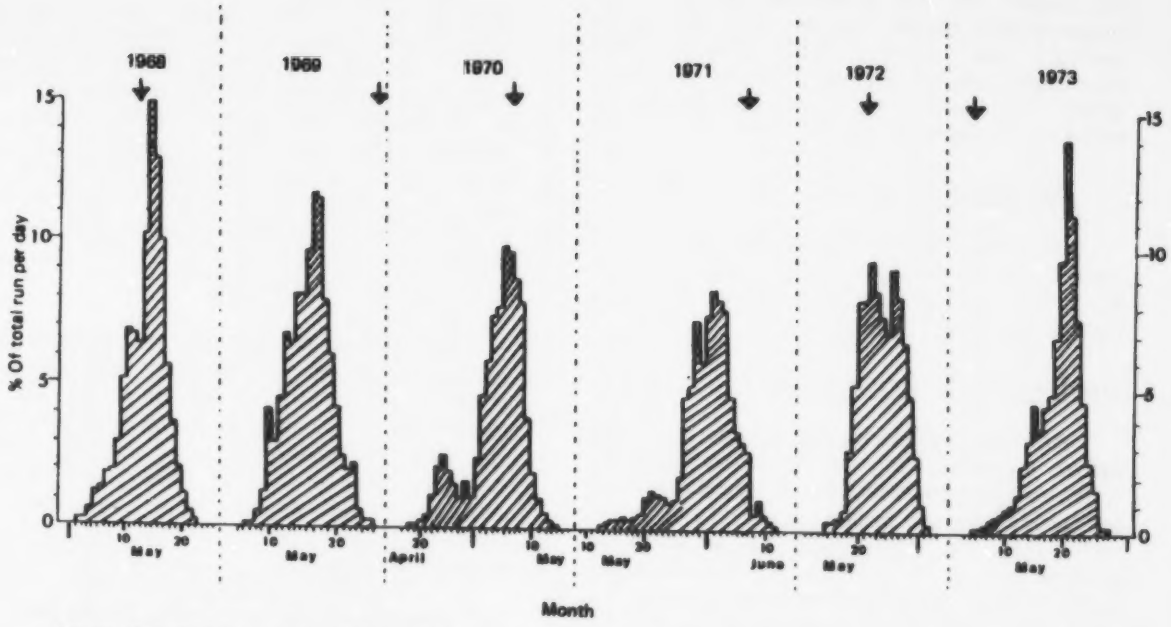


Fig. 32. Annual migration timing of chum fry from spawning channel No.2, 1968 – 1973 (arrows indicate 50% completion of river downstream migration).

Table 24. Swim tunnel stamina testing (minutes to exhaustion of river and channel No. 2 chum fry), 1970 brood.

Exhaustion (%)	River fry		Channel No. 2 fry		Difference (River-Channel)
	No. minutes (±1 S.D.)	Coefficient of variation (%)	No. minutes (±1 S.D.)	Coefficient of variation (%)	
20	0.44±.17	39	0.44±.17	39	0.00
40	0.77±.29	38	0.73±.21	29	0.04
50	0.94±.37	39	0.90±.31	34	0.04
60	1.13±.54	48	1.02±.32	31	0.11
70	1.43±.76	53	1.23±.41	33	0.19
80	1.71±.93	54	1.47±.47	32	0.24

different levels of exhaustion were substantially lower for channel fry compared to river fry in all except the 20% exhaustion group. This suggested that channel fry were more uniform in quality than river fry, although this relationship was not apparent from the length and weight data which had low coefficients of variation for both fry groups.

Chum egg-to-fry survival

The annual egg-to-fry survival of chum in channel No. 2 averaged 74.5% (range 60.6% - 90.1%; Table 23) and was three times higher than that in the river (Table 21).

Juvenile chum off-shore dispersal

Most chum fry leaving the Big Qualicum River system apparently migrate in a northwesterly direction along the shoreline of Vancouver Island and through channels between small islands in the region (Fig. 33). This dispersion was monitored by purse seining in 1969 and 1970 (Fraser et al. 1979). First appearance of juveniles in the small bays along Baynes Sound by early April to mid-May was followed by a peak two to six weeks later; no juveniles were observed by the end of June. Other fry passed through Lambert Channel or Tribune Bay. The mass of fish moved from the south to north end of Lambert Channel by mid-June and completely out of the channel by mid-August. The May peak in numbers in Tribune Bay had moved beyond St. John Point by the end of July. The first chum fry captured at Cape Lazo in 1970 were recovered on June 22, almost 16 weeks after commencement of the exodus from Big Qualicum River.

Available evidence indicated that by the end of August, Big Qualicum River chum fry were entirely absent from the Baynes Sound area and had shifted toward Johnstone and Queen Charlotte Straits (Fig. 34).

Marine survival of Big Qualicum River chum

Computations

Fry-to-adult survival of Big Qualicum River chum was determined by applying the age composition of returning adults to total catch and escapement. However, the Big Qualicum River system calculations were complicated by two factors. First, since 1962, more than one source of chum salmon was involved and it was desirable to distinguish fish produced in the river from those produced in either the spawning channels or in the hatchery and rearing facilities. Second, it was impossible to differentiate the Big Qualicum River fish caught by commercial fishermen from those of other rivers such as the Fraser. To solve both these problems a marking program was initiated in 1965 (see methods). The marking programs for 1964 to 1972 chum broods are summarized in Table 25. In total, some 11 million chum fry were marked in the spring of 1965 through 1973. The assumptions involved and the difficulties encountered during the marking program are recorded in the DFO Big Qualicum River file No. 5903-85-05-c.

The assignment of chum escapements and commercial catches to brood year and source of origin is discussed in Appendices 36 and 37 respectively. Commercial catch estimates are discussed in Appendix 37. Commercial catch estimates for the unmarked 1959 to 1963 broods which had no mark information were determined by backcalculation using mark return data for later broods (Append. 37).

In computing marine survival of Big Qualicum River chum by brood year for each component of the system (the river, two channels and freshwater-rearing facilities), both dead and live sample data were used where available (returns during the period 1970-1973). Only brood escapements, not catch totals were modified by the choice of live versus dead sample types. Furthermore, the total escapement estimates each year did not change with the method used but the distribution of escapement by age class and source of origin was affected.

The difference in survival estimates due to the methods used was particularly high (up to 21%) for the 1967 to 1969 broods; for example, survival of the 1969 brood channel 2 fry was 0.71% or 0.87% depending on the sample type selected; Table 27). The source of this variance is discussed in DFO, Big Qualicum River file No. 5903-85-05-c.

Chum escapement and commercial catches

Annual escapements and commercial catches of Big Qualicum River chum are summarized by brood year and source of origin in Table 26. Escapements to the total system ranged from a low of 17,900 chum for 1961 brood year to a high of 183,000 chum for 1969 brood year. Commercial catches for the total system ranged from a low of 300 for 1962 brood year to a high of 250,000 for

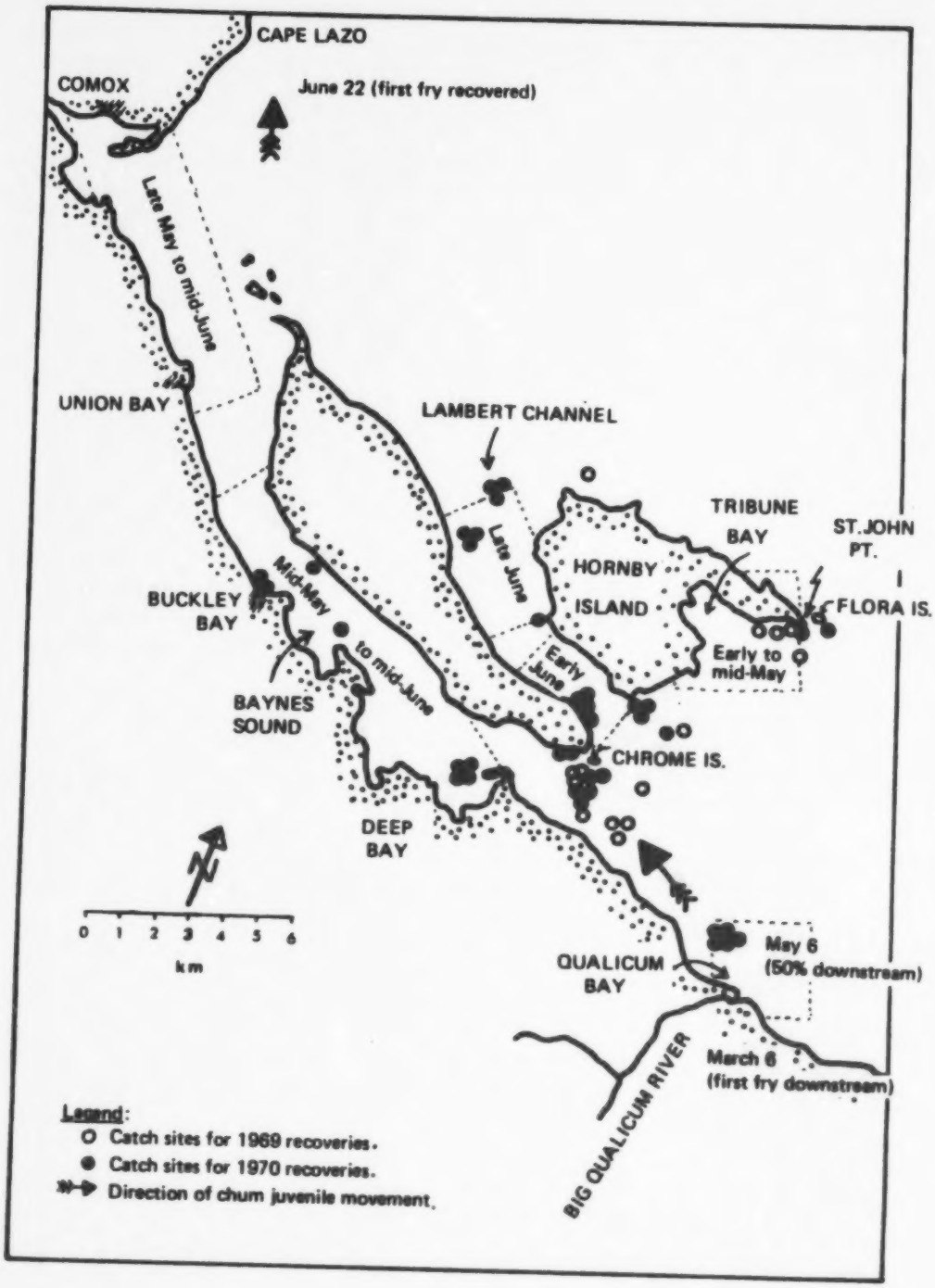


Fig. 33. Offshore distribution of Big Qualicum River marked chum fry in 1969 and 1970, and approximate dates of their peak abundance in specified sub-areas in 1970.

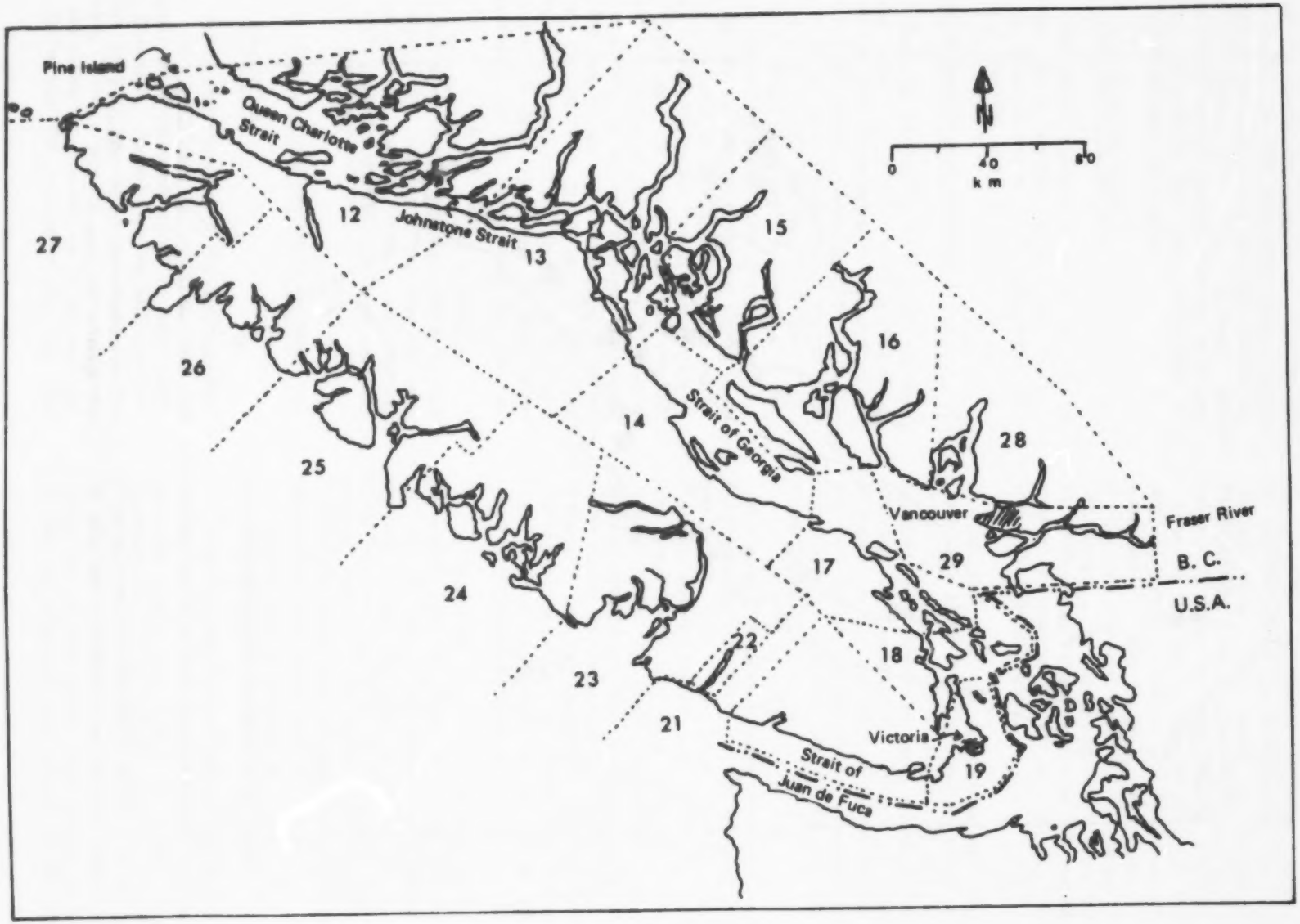


Fig. 34. Location of statistical fishing areas in southern British Columbia waters.

Table 25. Summary of Big Qualicum River chum fry marking programs, 1964 - 1972 broods.

Brood year	Mark type	Source of fry	No. marked	Live box survival after marking (%)	No. released	Total downstream migrants (millions)	Mark rate	No. released marks examined	Good quality adipose clips (%)[a]	Good quality anal or ventral clips (%)[a]	No. good marks released	Effective mark rate	Double clip mark rate
1964	Ad	River	762,857	98.5	751,400	15.3	4.91	4,785	98.3	-	738,600	0.0483	-
1965	Ad/RV	River	184,373	99.5[b]	183,500	9.58	1.91	3,538	99.2	80.6	147,900	0.0154	0.0303
	Ad/LV	Channel No. 1	193,901	99.7[b]	192,300	0.694	27.7	3,121	99.7	85.2	163,900	0.236	
1966	Ad/RV	River	419,344	99.7	404,000	20.7	1.95	11,487	100	94.6	396,300	0.0191	0.0250
	Ad/LV	Channel No. 1	154,253	99.8	153,900	1.14	13.5	3,549	100	98.4	151,500	0.133	
1967	Ad/RV	River	419,355	99.7	418,100	21.6	1.94	9,121	100	95.2	398,000	0.0184	
	Ad/LV	Channel No. 2	393,761	99.7	392,600	11.6	3.38	9,923	100	97.9	384,300	0.0331	0.0235
	Ad	Reared	21,403	81.3	17,400	0.176	9.88	0	100[d]	-	17,400	0.0989	
1968	Ad/LV	River	2,231,240	99.6	2,222,000	34.3	6.48	35,753	100	96.4	2,142,000	0.0624	
	Ad/RV	Channel No. 2	448,533	99.6	446,700	15.3	2.92	6,095	100	95.8	428,000	0.0280	0.0518
	Ad	Reared	84,248	81.1	68,340		3.27	0	100[d]	-	68,340	0.0327	
	Ad/Rn	Reared	122,900	96.3	113,400	2.09	5.43	0	100[d]	97.04	110,000	0.0526	
1969	Ad/LV	River	1,263,475	99.7	1,259,000	42.0	3.00	15,085	100	97.0	1,221,000	0.0291	
	Ad/RV	Channel No. 2	691,192	99.2	685,700	19.5	3.52	10,335	100	98.5	675,400	0.0346	0.0312
	Ad/Rn	Reared	156,007	46.9[c]	73,150[c]	1.60	4.57	2,475	99.9	97.0	70,980	0.0444	
1970	Ad/LV	River	917,315	99.7[b]	914,600	27.7	3.30	15,102	100	98.4	899,900	0.0325	0.0325
	Ad/RV	Channel No. 2	677,217	99.5[b]	673,800	20.4	3.30	11,685	100	98.5	663,700	0.0325	
1971	Ad/RV	Channel No. 2	995,671	99.1	986,300	17.5	5.64	0	100[d]	98.5[d]	971,600	0.0555	0.0555
1972	Ad/RV	Channel No. 2	1,000,961	99.5[b]	996,000	21.7	4.59	0	100[d]	98.5[d]	981,000	0.0452	0.0452

[a] Based on minimum percent good quality.
[b] Average of other years for the particular mark type.
[c] Fish were marked prior to the rearing period.
[d] Estimated from previous data.

Table 26. Annual number of fry migrants, and adult escapement, catch and total return of Big Qualicum River chum by brood year and source, 1959-1972 broods.

Brood year	Source	Total fry migrants (millions)	Escapement	Catch	Total return
1959	River	21.1	68,800	29,000	98,000
1960	River	4.6	37,100	11,000	48,000
1961	River	4.6	17,900	1,300	19,000
1962	River	6.9	43,700	300	44,000
1963	River	19.2	44,900	4,800	50,000
	Channel No. 1	1.8	4,890	520	5,400
	System	21.0	49,800	5,300	55,000
1964	River	15.3	115,000	35,000	150,000
	Channel No. 1	0.1	923	281	1,200
	System	15.4	116,000	35,300	152,000
1965	River	9.6	83,200	52,100	135,000
	Channel No. 1	0.7	6,790	3,690	10,500
	System	10.3	90,000	55,800	146,000
1966	River	20.7	163,000	128,000	291,000
	Channel No. 1	1.1	14,000	7,220	21,200
	System	21.8	177,000	135,000	312,000
1967	River	21.6	66,100	10,900	77,000
	Channel No. 2	11.6	29,800	4,320	34,100
	System	33.9	96,200	15,200	111,000
1968	River	34.3	81,100	118,000	199,000
	Channel No. 2	15.3	36,100	74,200	110,000
	Reared	2.1	4,250	6,730	11,000
	System	51.7	123,000	199,000	322,000
1969	River	42.0	125,000	155,000	280,000
	Channel No. 2	19.5	53,600	84,100	138,000
	Reared	1.6	3,790	11,300	15,100
	System	63.1	183,000	250,000	433,000
1970	River	27.7	18,400	4,640	23,050
	Channel No. 2	20.4	6,750	2,340	9,090
	System	48.1	25,150	6,980	32,140
1971	River	19.2	43,700	18,470	62,160
	Channel No. 2	17.5	45,800	19,520	65,320
	System	36.7	89,500	37,990	127,480
1972	River	21.9	70,570	52,370	122,940
	Channel No. 2	21.7	69,080	51,970	121,050
	System	43.6	139,650	104,340	243,990

Table 27. Marine survival of Big Qualicum River chum salmon, 1959 - 1972 broods.

Brood year	Survival (%) based on live sample data wherever possible[a]				Survival (%) based on dead sample data wherever possible			
	River	Channel No. 1	Channel No. 2	System[b]	River	Channel No. 1	Channel No. 2	System[b]
1959	0.46	-	-	0.46	0.46	-	-	0.46
1960	1.05	-	-	1.05	1.05	-	-	1.05
1961	0.42	-	-	0.42	0.42	-	-	0.42
1962	0.64	-	-	0.64	0.64	-	-	0.64
1963	0.26	0.30	-	0.26	0.26	0.30	-	0.26
1964	0.98	1.15	-	0.98	0.98	1.17	-	0.98
1965	1.41	1.51	-	1.42	1.41	1.51	-	1.41
1966	1.41	1.86	-	1.43	1.43	1.94	-	1.45
1967	0.36	-	0.29	0.33	0.36	-	0.34	0.34
1968	0.58	-	0.72	0.62	0.54	-	0.81	0.62
1969	0.67	-	0.71	0.69	0.57	-	0.87	0.67
1970	0.08	-	0.04	0.07	0.08	-	0.04	0.07
1971	0.32	-	0.37	0.35	0.32	-	0.37	0.35
1972	0.56	-	0.56	0.56	0.56	-	0.56	0.56
Mean	0.66	1.21	0.45	0.66	0.65	1.23	0.50	0.66

[a] Computed using Table 26 data; live sampling involved 1965 and later broods only.
b Includes freshwater reared chum from broods 1968 and 1969.

1969 brood year.

The estimated annual catch of Big Qualicum River chum was low during the early years of the project (generally below 50,000 fish) and reflected the depressed condition of the Johnstone Strait - Fraser River chum stocks (Table 28). Exploitation rates of Big Qualicum River chum ranged from 0.3% in 1966 to 67.1% in 1972, and were usually high in years of abundant returns (Table 28).

Chum marine survival

The fry-to-adult survival rates of chum from the Big Qualicum River system were estimated using net fry downstream total counts derived from chum fry production numbers corrected for mortality during trapping, marking and fry removal for rearing studies (Append. 23).

The marine survival of chum salmon from the Big Qualicum River system for 1959 to 1972 broods averaged 0.66% (range 0.07% - 1.43%; Table 27). Individual survival rates for the river, channel No. 1 and channel No. 2 fry, based on live sample data wherever possible, averaged respectively 0.66% (range 0.08% - 1.41%), 1.21% (range 0.30% - 1.86%) and 0.45% (range 0.04% - 0.72%). Computations based on dead sample data wherever possible gave similar survival results (Table 27).

Pre and post-flow control survivals of river fry were similar at 0.64% and 0.66% respectively (Table 29). Channel No. 1 fry survived at a rate of 1.21% compared to 1.02% for river fry of the 1963 to 1966 broods, but within group variance was sufficient to make this difference statistically insignificant. Similarly, there was little difference in the survival of channel No. 2 (0.45%) and river chum fry (0.43%) for the 1967 to 1972 broods (Table 29).

COHO SALMON

Coho salmon in Big Qualicum River

Coho escapement

During 1947 to 1958, prior to project development, annual coho escapement to the Big Qualicum River system averaged 3,300 fish (Table 1). During 1959 to 1972, annual coho escapement to the system averaged 3,900 fish and to the main river 3,000 fish (range 1,200 - 7,400; Table 30). Mean escapement to the mainstem was approximately five times greater than to Hunt's Creek (Table 30).

Escapements of age 2 jack males are included in Table 30, but they may be underestimated because some jacks were very small (250 mm) and could pass uncounted through the fence. Jack populations in 1959 and 1960 were estimated from age composition data, while in later years fence estimates were made.

Coho adult migration timing, river life-span and spawning distribution

The overall mean (±1 S.D.) dates for commencement, 50% completion and total completion of the coho run into Big Qualicum River were September 16 ± 10 days, October 28 ± 9 days and December 30 ± 17 days respectively; mean (± 1 S.D.) duration of the run was 106 ± 21 days, or about one month longer than the chum run (82 days) and five weeks longer than the chinook run (70 days; Fig. 24, Table 31). As was observed for chum, upstream migration of coho was longer after flow control than before (113 days vs 87 days), but no significant change was recorded in the date of 50% completion of the run (Table 32).

Coho moved upstream throughout the day but peak numbers at hub 290 were apparent at dawn and dusk on most sampling dates.

Death of spawned out Big Qualicum River coho occurred approximately 33 days after leaving the sea. The period between peak migration past the fence and peak spawning ground count was 21.5 days (range 16 - 32 days during four years of observation). Peak spawning occurred 11 days later (range 7-16 days during four years of observation). Subsequent die-off occurred within a day or two.

Coho spawners were found throughout the river above hub 290, but were most abundant in section 1 (24% of total coho spawners) and in Hunt's Creek (28%) (Fig. 25, Table 9). Their density was highest in section 4, immediately upstream of Hunt's Creek outlet (927 fish/km of river length), with secondary peaks observed in section 1 and Hunt's Creek (Table 9).

Coho adult age, length and sex composition

Most coho returns to the Big Qualicum River were age 3 (79.4% during the 14-year period) but age 2 jacks accounted for about 50% of the escapement in 1970 and 1972 (Table 31). In

Table 28. Annual commercial catch of chum salmon in Johnstone Strait - Fraser River areas, and Big Qualicum River annual chum catch, escapement and exploitation rates, 1962 - 1975.

Return year	Total Johnstone Strait - Fraser River catch[a]	Big Qualicum River		
		Catch	Escapement	Exploitation (%)
1962	91,185	7,950	47,141	14.4
1963	217,221	29,600	37,681	44.0
1964	101,499	4,780	36,548	11.6
1965	17,235	300	18,915	1.6
1966	20,324	170	53,843	0.3
1967	98,436	7,220	43,215	14.3
1968	497,657	30,354	140,384	17.8
1969	454,522	107,246	101,016	51.5
1970	695,534	91,901	132,325	41.0
1971	42,200	5,220	106,022	4.7
1972	1,709,330	164,186	80,513	67.1
1973	2,231,569	288,521	163,956	63.8
1974	113,896	10,531	96,396	9.8
1975	202,316	40,836	109,950	27.1

[a] Includes only fisheries expected to include Big Qualicum River fish and exceeding total catch of 500.

Table 29. Comparison of marine survival of Big Qualicum River chum before and after flow control in the river and the spawning channels, 1959 - 1972 broods.

Broods	Period	Marine survival ± 1 S.D. (%)		
		River	Channel No. 1	Channel No. 2
1959 - 62	Pre-control	0.64±0.29	-	-
1963 - 72	Post-control	0.66±0.47	-	-
1963 - 66	Post-control	1.02±0.54	1.21±0.67	-
1967 - 72	Post-control	0.43±0.22	-	0.45+0.27

Table 30. Annual coho escapement to the Big Qualicum River system, 1959 - 1972.

Year	Main river			Spawning channels[a]			Holdings pond			Hunt's Creek			System		
	Adults	Jacks	Total	Adults	Jacks	Total	Adults	Jacks	Total	Adults	Jacks	Total	Adults	Jacks	Total
1959	2,311	463	2,774	-	-	-	-	-	-	708	142	850	3,019	605	3,624
1960	1,179	203	1,382	-	-	-	179	0	179	900	100[b]	1,000	2,258	303	2,561
1961	1,476	510	1,986	-	-	-	-	-	-	810	90[b]	900	2,286	600	2,886
1962	3,316	295	3,611	-	-	-	-	-	-	904	100[b]	1,004	4,220	395	4,615
1963	159[c]	231[c]	390[c]	57	4	61	-	-	-	811	90[b]	901	1,027[c]	325[c]	1,352[c]
1964	3,836	345	4,181	98	2	100	2	0	2	933	24	957	4,869	371	5,240
1965	2,767	635	3,402	100	0	100	-	-	-	255	64	319	3,122	699	3,821
1966	3,405	520	3,925	66	0	66	-	-	-	864	109	973	4,335	629	4,964
1967	1,123	282	1,405	13	0	13	30	0	30	180	20[b]	200	1,346	302	1,648
1968	2,066	218	2,284	14	5	19	132	0	132	169	12	181	2,381	235	2,616
1969	1,047	267	1,314	34	2	36	605	61	666	135	15[b]	150	1,821	345	2,166
1970	2,317	2,331	4,648	48	28	76	659	0	659	103	11	114[d]	3,127	2,370	5,497
1971	6,927	455	7,382	34	6	40	1,375	7	1,382	299	34	333[d]	8,635	502	9,137
1972	597	591	1,188	-	-	-	429	16	445	-[e]	-[e]	-[e]	1,026	607	1,633
Mean[f]	2,490	547	3,037	-	-	-	-	-	-	544	62	606	3,265	613	3,878

[a] Channel No. 1, 1963 - 66;
Channel No. 2, 1967 - 71.
[b] Estimated.
[c] Incomplete data since high discharge during adult migration prevented a complete count; these data excluded from escapement averages.
[d] Based on distribution counts.
[e] No population estimate available.
[f] Main river and system means excluding 1963 data.

Table 31. Coho adult migration timing, brood stock characteristics and egg deposition in Big Qualicum River above hub 290, 1959 - 1972 broods.[a]

Brood year	Duration of migration	Date of 50% river migration	Age Composition (%)		Length (mm) at age		Females[b] (%)	Mean fecundity (eggs/female)	Egg retention (%)	No. females[c]	Actual egg deposition (millions)
			2	3	2	3					
1959	78	Nov. 2	16.7	83.3	298	512	52.6	1758	25.4	1216	1.60
1960	81	Oct. 23	-	-	-	-	-	2003	47.5	657	0.69
1961	90	Oct. 26	25.7	74.3	284	524	57.8	1888	29.2[d]	853	1.14
1962	99	Oct. 19	8.2	91.8	323	572	55.3	2463	14.7	1834	3.85
1963	74	Oct. 15	-	-	428	566	72.7	2964	8.5	157[e]	-[e]
1964	134	Oct. 29	8.3	91.7	-	560	53.5	3060	14.6	2105	5.50
1965	100	Oct. 30	18.7	81.3	337	574	53.6	3089	8.4	1537	4.35
1966	124	Nov. 14	13.2	86.8	330	520	51.1	2552	24.1	1774	3.44
1967	96	Oct. 30	20.1	79.9	-	476	44.6	3741	28.2	507	1.36
1968	114	Oct. 29	9.5	90.5	-	493	50.5	2264	26.1	1050	1.76
1969	111	Oct. 28	20.3	79.7	427	521	67.9	2994	18.3[f]	734	1.80
1970	119	Nov. 8	50.2	49.8	341	536	58.1	2631	18.3[f]	1374	2.95
1971	144	Nov. 3	6.2	93.8[g]	355	499	-	2422	18.3[f]	3877	7.67
1972	113	Oct. 10	49.7	50.3	293	500	50.7	2209	18.3[f]	303	0.55
Mean ± 1 S.D.	106±21	Oct. 28±9	20.6±14.9	79.4±14.9	342±51	527±32	55.7±7.8	2574±549	22.0±12.2	-	2.82±2.10

[a] See Append. 38 - 42 for details.
[b] Proportion of returns excluding jacks.
[c] Including spawning channel adults.
[d] Mean of pre-flow control years; excluded from calculating overall mean.
[e] Incomplete escapement data.
[f] Mean of post-flow control years; excluded from calculating overall mean.
[g] Age 4 returns accounted for 0.5% of this group.

Table 32. Comparison of biological parameters for coho salmon in Big Qualicum River before and after flow control, 1959-1972 broods.

Parameter	Before flow control		After flow control		Wilcoxon's U-Statistic[a]
	Broods included	Mean ± 1 S.D.	Broods included	Mean ± 1 S.D.	
Adult escapement					
- duration (days)	1959-62	87±10	1963-72	113±20	35*
- 50% completion	1959-62	Oct. 25±6	1963-72	Oct. 29±10	27 n.s.
Egg retention (%)	1959,60,62	29.2±16.7	1963-68	18.3±8.9	13 n.s.
Egg incubation					
- duration days	1959-62	160±7	1963-72	169±12	30 n.s.
- thermal units (°C-days)	1959-62	1,118±213	1963-72	1,004±91	28 n.s.
- mean temperature (°C)	1959-62	7.0±1.1	1963-72	5.9±0.6	32 n.s.
Fry migration					
- 50% completion	1959-62	May 4±9	1963-72	May 17±15	30.5 n.s.
Migrant smolts					
- length (mm)	1958-62	94.6±3.1	1963-72	100.5±5.9	41*
- weight (g)	1959-61	9.26±0.59	1963,64,67-72	11.91±2.49	21*
- condition (mg/mm^3)	1959-61	1.109±0.040	1963,64,67-72	1.114±0.025	13 n.s.
- duration of migration (days)	1958-62	92±28	1963-72	132±17	48**
- 50% completion of migration	1958-62	May 24±5	1963-72	May 28±4	37.5 n.s.
Egg-to-smolt survival (%)	1961, 62	1.42±1.03	1964-72	1.66±1.73	9 n.s.
Smolt-to-adult escapement survival (%)	1958-62	12.0±4.3	1963-72	10.2±2.8	33 n.s.

[a] n.s. $p > 0.05$
* $0.05 > p > 0.01$
** $p < 0.01$

addition, scale analysis indicated that age 4 adults were also present in some Big Qualicum River returns and that these fish spent two years in freshwater as juveniles compared to the usual one year. Returns of tagged coho at age 4 confirmed the existence of this age class (only two 4-year olds were recovered up to 1970, but 42 were estimated in 1971, 87 in 1973, and 2,173 in 1974; the latter year also had by far the largest escapement).

Pritchard (1940) reported that ages 2, 3 and 4 contributed 0.2%, 98.1%, and 1.7% respectively to the coho commercial catch in British Columbia (contribution of jacks was low since they are usually under legal size limits). The older age composition of 4, 5, or 6 years, observed for coho stocks from Karluk River, Kodiak Island, suggests the existence of a north-south cline (Drucker 1972).

The length of coho jacks averaged 342 mm, while age 3 adults averaged 527 mm (Table 31). The mean length (± 1 S.D.) of four age 4 adults sampled in 1971 was considerably larger (566 ± 47 mm) than that of age 3 fish sampled that year (499 ± 53 mm). Three year old males and females had similar lengths (Append. 40 and 41). Age classes of the coho populations were usually separated on the basis of size. Shapovalov and Taft (1954) and Burck (1967) found that age classification of coho (ages 2 or 3) on the basis of length was at least 98% efficient.

Females comprised on the average 55.7% (range 44.6% - 72.7%) of the river coho spawners (Table 31); however, when jacks were abundant, as in 1974, females constituted as little as 25% of the total escapement. (Only large fish, excluding jacks, were sampled for sex since both live catches at the fence and dead pitches from the spawning grounds were biased against jacks). Sex composition of sampled age 4 coho returning in 1971 to 1974 averaged 51.9% females.

Coho fecundity, egg retention and deposition

Coho females were sampled for fecundity during seven years of the 1959 to 1972 study period; samples from 1959 to 1962 were pooled due to insufficient data (Append. 43). An overall linear regression based on all the accumulated data was used in years for which no specific relationship was available.

Annual coho fecundity at the Big Qualicum River averaged 2,574 eggs (range 1,758 - 3,741; Table 31). The wide range of annual fecundity estimates was due to the considerable variation in the annual mean size of Big Qualicum River coho females (495 mm - 661 mm; Append. 41).

The above mean fecundity compares well with data from similar geographical regions: a range per female coho of 2,310 eggs (mean for five broods from Mile Creek; Wickett 1951) to 3,152 eggs (mean for 48 Fraser River coho; Foerster and Pritchard 1936). Drucker (1972) reviewed the available fecundity data for North American coho stocks and found a trend to increased egg content in more northerly populations; female coho in California and Oregon averaged as few as 2,000 eggs while some Alaskan populations averaged 4,700 eggs. This contrasts with the suggestion by Rounsefell (1957) that the opposite response along a north-south cline was true for salmonids.

Egg retention of Big Qualicum River coho was extremely high averaging 22.0% (range 8.4% - 47.5%; Table 31). Mean retention appeared to be lower after flow control (18.3%) than before (29.2%) but this difference was not significant (Table 32). Shapovalov and Taft (1954) noted that egg retention, which averaged 60 eggs per female coho in Waddell Creek, California, was not an important source of mortality. The comparable retention figure for Big Qualicum River coho was 253 to 941 eggs per female and suggests that environmental factors in that river interfered seriously with spawning success.

The estimated actual egg deposition in the Big Qualicum River, including contribution by the few coho entering the spawning channels, averaged 2.82 million eggs per year (range 0.55 million -7.67 million; Table 31).

Coho egg incubation

The incubation period of coho was calculated as for chum, from median spawning date (32 days after peak adult migration past hub 290) until the median date of fry migration past hub 290. Coho eggs incubated from December to May for an average of 167 days (range 149 - 188 days); temperatures during this period averaged 6.2°C (range 5.3°C - 8.2°C); and A.T.U.'s averaged 1,036°C-days (range 834 - 1,402°C-days) (Fig. 24, Table 33).

After flow control, when the mean incubation temperature dropped from 7.0°C to 5.9°C, the A.T.U. requirements declined from 1,118 to 1,004°C - days, and the length of incubation

Table 33. Coho egg incubation, juvenile enumeration and sampling, and egg-to-smolt survival in Big Qualicum River, 1958 - 1972 broods.[a]

Principal brood year	Mean incubation temperature (°C)	Incubation period (days)	Accumulated thermal units (°C-days)	Migrant fry		Migrant smolts						Egg-to-smolt survival (%)
				Number (x 1000)	Date of 50% migration	Number (x 1000)[b]	Date of 50% migration	Duration of migration (days)	Mean length (mm)	Mean weight (g)	Condition coefficient	
1958	-	-	-	-	-	10.0	May 27	47	98.6	-	-	-
1959	7.1	157	1115	-	May 8	29.3	May 16	90	94.6	9.83	1.12	-
1960	8.2	171	1402	-	May 13	24.6	May 24	115	90.6	8.65	1.15	-
1961	5.6	159	890	-	May 4	24.5	May 23	93	96.5	9.29	1.07	2.15
1962	6.9	154	1063	0	Apr. 22	25.8	May 28	114	92.7	-	-	0.70
1963	6.8	173	1176	311.0	May 6	29.1	May 30	109	109.3	14.44	1.10	-
1964	5.9	173	1021	517.0	May 21	23.2	May 26	137	104.7	15.18	1.12	0.42
1965	6.2	164	1017	630.0	May 11	22.6	May 28	121	96.4	-	-	0.52
1966	5.6	149	834	310.0	May 13	12.8	May 26	127	101.1	-	-	0.37
1967	5.8	167	989	149.0	May 15	34.9	June 6	155	108.4	14.26	1.12	2.56
1968	5.3	188	996	127.0	June 5	53.2	May 23	162	96.7	9.93	1.10	3.03
1969	7.0	156	1092	63.0	May 3	13.3	May 29	120	98.7	11.03	1.13	0.74
1970	5.6	180	1008	87.2	June 7	28.8	May 28	119	98.0	11.04	1.17	0.98
1971	5.6	179	1002	1,630.0	May 31	99.7	May 27	137	90.0	8.01	1.10	0.78
1972	5.6	185	934	15.6	Apr. 24	30.1[c]	May 24	134	101.5	11.37	1.09	5.47
Mean ± 1 S.D.	6.240.8	167±11	10384138	347.04488.0	May 13±14	29.941.6[d]	May 2±5	119±28	98.5±5.8	11.1±2.44	1.11±0.03	1.61±1.59

[a] See Append. 44-46 for details.
[b] Including Hunt's Creek migrants for 1958-60 broods; excluding smolt productions below hub 290.
[c] Downstream migrants enumerated at new fence (hub 297).
[d] Excluding 1958-60 broods.

period increased from 160 to 169 days (Table 32). The above pre- and post-flow control differences in A.T.U.'s requirements and length of incubation period were not significant ($p > 0.05$).

Coho juvenile production and migration timing

The number of coho fry migrating past the main fence above hub 290 averaged 347,000 annually (range 0 - 1,620,000); the number of coho smolts migrating past the fence averaged 29,900 annually (range 12,800 - 59,700; Table 33). Although numbers of juvenile migrants varied considerably among the years, no consistent response related to the development of flow control was evident (Table 33).

Total coho fry production in the river could not be determined since many fry remained upstream to rear and rearing mortality was not determined. Also, prior to 1963, Hunt's Creek migrants were not counted as a discrete unit, so that the system downstream totals could not be fractioned into source of origin.

The river below the main fence at hub 290 was not considered to support any coho spawners, but did provide suitable rearing for coho fingerlings. Many coho fry counted through the main fence probably established themselves in this section of the river. The size of this population was estimated by assuming that the rearing capacity per unit river length was the same above and below the fence. Thus, given that 16,100 smolts emigrated from the upper river in 1968, the number of smolts produced below the fence from the 1966 brood year would be 1,000 (i.e. 16,100 smolts x 793 m/9934 m) where 793 m and 9934 m are the lengths of river below and above hub 290 respectively. In 1974, when smolts were enumerated at hub 297 instead of hub 290 (Fig. 4), virtually the entire coho population was sampled. Smolt production in the river below hub 290 averaged 2,150 fish (range 1,000 - 4,660; Append. 46).

Coho fry and smolts usually migrated between March and July, with mean 50% completion of their respective runs on May 13 and May 26 (Fig. 24, Table 33). However, in 1968, 1970 and 1971, fry migrations peaked later than those of smolts (Table 33). Mid-timing of fry and smolt downstream runs did not change significantly after flow control (Table 32). Duration of smolt downstream run averaged 119 days (range 47 - 162 days; Table 33) and increased significantly ($p < 0.01$) after flow control from 92 days to 132 days (Table 32).

Coho juvenile size and age composition

Coho fry that migrated from early March to late May generally averaged 35 mm to 37 mm and 0.4 g but after this period, a sharp rise in size occurred (up to 60 mm and 3.0 g; Fig. 35) indicating that some rearing between emergence and downstream migration took place. Migrant coho smolts averaged 98.5 mm (range 90.0 mm - 109.3 mm) and 11.2 g (range 8.0 g. - 15.2 g.); their condition coefficient averaged 1.11 (range 1.07 - 1.15; Table 33).

Coho smolts leaving the Big Qualicum River were on the average 6% longer and 29% heavier after introduction of flow control than before (Table 32). However, some of the above size differential is due to the inclusion of Hunt's Creek smolts in the pre-flow control river population samples (Hunts' Creek smolts were significantly smaller (86.2 mm, 7.3 g) than those produced in the river (98.9 mm, 11.5 g; Table 36). This interference occurred because prior to 1963, Hunt's Creek migrants were not sampled as a discrete unit. Also, from 1964 to 1970, a variable number of Hunt's Creek smolts migrated through the flood channel bypassing the main fence. Nevertheless, sampled river smolts were undoubtedly larger after flow control, and considerable variation in size occurred from year to year.

Among the river coho smolts migrants sampled between 1964 and 1973, an average of 98.4% were yearlings (1+), while the remainder were age 2+ (Table 34). No pre-flow control age measurements were available for comparison. Scales taken from coho smolts leaving the neighbouring Little Qualicum River in 1973 showed that 92.9% were age 1+ and 7.1% were age 2+. Pritchard (1940) estimated on the basis of scale readings that 0.4% of a sample of 6312 commercially captured coho migrated to sea as fry, 98.7% as 1+ smolts and 0.9% as 2+ smolts. Foerster and Ricker (1953) reported that very few age 2+ smolts were produced in Cultus Lake, B.C., while Shapovalov and Taft (1954) found that all smolts produced in Waddell Creek, California, were age 1+. Coho smolt samples in the Karluk River, Kodiak Island, consisted of 57% age 2+, 42% age 3+ and 1% age 4+, indicating slower growth in the Alaskan environment (Drucker 1972).

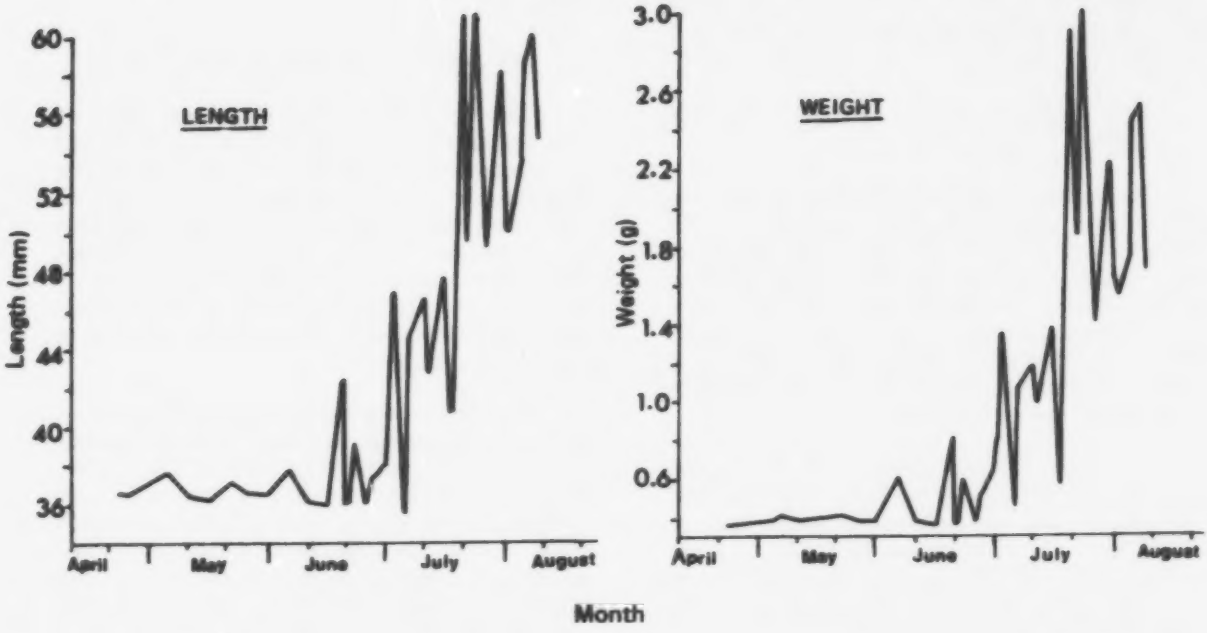


Fig. 35. Mean length and weight of coho fry migrating past the main fence in Big Qualicum River, April – August 1971.

Table 34. Age composition of coho smolts migrating from Big Qualicum River and Hunt's Creek, 1964-1973.

	Main River			Hunt's Creek		
Year	Sample size	Age 1+ (%)	Age 2+ (%)	Sample size	Age 1+ (%)	Age 2+ (%)
1964	30	100.0	0.0	54	94.4	5.6
1966	74	97.3	2.7	47	97.9	2.1
1967	119	99.2	0.8	166	97.6	2.4
1968	41	100.0	0.0	50	98.0	2.0
1973	347	95.4	4.6	423	97.2	2.8
Mean ± 1 S.D.	-	98.4±2.0	1.6±2.0	-	97.0±1.5	3.0±1.5

The above smolt age data for Big Qualicum River revealed a source of error in the juvenile downstream analysis since all migrating smolts were assumed to be age 1+ and were assigned to brood year on that basis. However, due to scarcity of data, no attempt was made to correct this relatively minor error.

Coho egg-to-smolt survival

The annual egg-to-smolt survival of Big Qualicum River coho, based on actual egg deposition, averaged 1.61% (range 0.3% - 5.47%; Table 33) and did not differ significantly before and after flow control (Table 32). These rates are a measure of the river's rearing capacity above hub 290 rather than of successful incubation. (Hunt's Creek fry could enter the river prior to 1971, after which year the creek was sealed from the main river at hub 200). In addition, both river-and creek-spawned fry may have reared in the lower river.

Coho salmon in Hunt's Creek

Coho escapement

Coho were the only salmonid species, other than steelhead trout, utilizing Hunt's Creek (28% of total coho spawners before flow control; Table 9). During 1959 to 1971, annual coho escapement (excluding jacks) to Hunt's Creek averaged 544 fish (range 103 - 933; Table 30). Coho spawning population in Hunt's Creek declined markedly since 1964, possibly as a result of the development project. It is probable that coho avoided the live trap positioned in the creek just above the confluence with the main river, and thus did not reach their destination. In 1970, the mouth of the flood channel was modified to allow escapement via this route in an attempt to rehabilitate this coho stock. However, data on coho escapement to Hunt's Creek since that time are limited.

Coho adult age, length and sex composition

Most coho returns to Hunt's Creek were age 3 (mean 89.9%), and averaged 536 mm at that age (Table 35). Females comprised on the average 48.4% of the creek coho spawners (Table 35). No significant differences were observed between age, length and sex composition of adults in the creek and those in the river, but females comprised on the average 9% less of the 1962 to 1966 escapements to the creek compared to the river (Table 36). This difference was the result of a bias from a very high female component in the 1963 river population (72.7%; Table 31) and a very low female component in the 1965 creek population (37.7%; Table 35).

Coho fecundity, egg retention and deposition

Fecundity of Hunt's Creek coho was calculated by applying the fecundity-length regression equations found for the Big Qualicum River coho to the six years when creek female length data were available; in other years, river population fecundity estimates were used. Annual mean fecundity of coho in Hunt's Creek, based on actual creek data, ranged from 1,765 to 2,964 eggs per female (Table 35).

Mean egg retention of Hunt's Creek coho, measured for four years, was much lower (3.5%) than concurrent river data (15.5%) (Tables 35 and 36), indicating a more favourable spawning environment in the creek. Retention in Hunt's Creek averaged 55 eggs per female in 1962, 1963 and 1966, which is comparable to 60 eggs per female found by Shapovalov and Taft (1954) for coho in Waddell Creek, California.

The estimated actual egg deposition in Hunt's Creek each year until 1964 ranged from 0.58 million to 1.29 million (Table 35). This range reflects variation in female length, and therefore fecundity estimates, rather than variation in numbers of females. After 1964, deposition remained below 0.4 million eggs, except in 1966 when 0.89 million eggs were deposited (Table 35). The poor loadings in later years were due to reduction in the number of spawners by up to 90%, compared to the first six years of the study (Table 30).

Coho egg incubation

Sufficient temperature data were not available for estimating incubation periods and thermal unit requirements for Hunt's Creek coho.

Coho juvenile production and migration timing

The number of coho fry migrating from Hunt's Creek averaged 76,000 fish annually during 1962 to 1964 brood years, but dropped considerably after 1964 (Table 37) when the spawning population declined (Table 30). An exception was the large 1971 brood migration (77,300 fry) possibly resulting from fry transplants to Hunt's Creek. (Coho fry incubated in the Big Qualicum

Table 35. Coho brood stock characteristics and egg deposition, in Hunt's Creek, 1959-1972 broods.[a]

Brood year	Females[b] (%)	Age composition (%) 2	3	Length (mm) at age 2	3	Mean fecundity (eggs/female)	Egg retention (%)	No. females	Mean length females (mm)	Actual egg deposition (millions)
1959	-	-	-	-	516	1,765	3.5[d]	343	496	0.58
1960	-	-	-	-	-	2,003[c]	3.5[d]	436	527[c]	0.84
1961	-	-	-	-	-	1,888[c]	3.5[d]	392	512[c]	0.71
1962	55.0	-	-	357	594	2,609	2.0	497	606	1.27
1963	52.5	-	-	487	559	2,964	1.7	426	570	1.24
1964	50.5	2.5	97.5	-	554	2,964	7.8	471	570	1.29
1965	37.7	20.1	79.9	-	-	3,089[c]	3.5[d]	96	583[c]	0.29
1966	46.2	11.2	88.8	-	520	2,283	2.5	399	499	0.89
1967	-	-	-	-	-	3,741[c]	3.5[d]	87	651[c]	0.31
1968	-	6.6	93.4	-	475	2,264	3.5[d]	82	497	0.18
1969	-	-	-	-	-	2,994[c]	3.5[d]	65	523[c]	0.19
1970	-	-	-	-	-	2,631[c]	3.5[d]	50	532[c]	0.13
1971	-	-	-	-	-	2,422[c]	3.5[d]	145	500[c]	0.34
1972[e]	-	-	-	-	-	-	-	-	-	-
Mean ± 1 S.D.	48.4±6.8	10.1±7.6	89.9±7.6	422±92	536±41	2585±560	3.5±2.9	-	-	0.64±0.44

[a] See Append. 47-49 for details.
[b] Proportion of returns excluding jacks.
[c] Comparative river figures.
[d] Mean of other years; excluded from calculating overall mean.
[e] Adults not counted or sampled.

Table 36. Comparison of biological parameters for coho salmon in Hunt's Creek and Big Qualicum River, 1959-1972 broods.

Parameter	Broods compared	Hunt's Creek Mean ± 1 S.D.	Big Qualicum River Mean ± 1 S.D.	Wilcoxon's U-Statistic
Adult sampling				
- length females (mm)	1959,62,63,64,66,68	536±41	543±42	20 n.s.
- age (%age 3)	1964,65,66,68	89.9±7.6	87.6±4.7	10 n.s.
- females (%)	1962-66	48.4±6.8	57.2±8.8	21 n.s.
Egg retention (%)	1962,63,64,66	3.52±2.90	15.5±6.4	16 *
Fry migration				
- 50% completion	1962-68	May 8±8	May 13±14	32 n.s.
Migrant smolts				
- length (mm)	1961-66,69-72	86.2±5.6	98.9±5.6	95 **
- weight (g)	1961,63,64,69-72	7.32±0.87	11.48±2.57	47 **
- condition (mg/mm^3)	1961,63,64,69-72	1.09±0.07	1.11±0.03	30 n.s.
- age (%age 2+)	1964,66,67,68,73[b]	3.0±1.5	1.6±2.0	18 n.s.
- 50% completion of downstream run	1961-67,69,70,72	May 15±7	May 28±4	96.5 **
Egg-to-smolt survival (%)	1961,62,64-68	0.92±0.71	1.39±1.14	31 n.s.

[a] n.s. $p > 0.05$
* $0.05 > p > 0.01$
** $p < 0.01$

[b] Year of downstream migration.

Table 37. Coho juvenile enumerations and sampling, and egg-to smolt survival in Hunt's Creek, 1961-1972 broods.[a]

Brood year	Migrant fry		Migrant smolts					
	Number (x 1000)	Date of 50% migration	Date of 50% migration	Mean length (mm)	Mean weight (mg)	Condition coefficient	No. smolts (x 1000)	Egg-to-smolt survival (%)
1961	-	-	May 7	82.9	6.59	1.14	7.26	1.02
1962	77.3	Apr. 30	May 15	81.0	4.32	1.21	5.01	0.39
1963	73.5	Apr. 29	May 15	83.6	6.80	1.15	4.38	0.35
1964	81.2	May 21	May 16	80.6	6.16	1.18	5.93	0.46
1965	31.7	May 11	May 5	77.7	-	-	4.99	1.74
1966	68.6	May 9	May 16	90.8	-	-	5.69	0.64
1967	1.3	May 14	May 7	-	-	-	0.60	0.19
1968	33.3	May 4	-	-	-	-	3.62	2.02
1969	3.8	-	May 26	93.1	8.60	1.07	3.80[c]	2.02
1970	0.1	-	May 17	89.7	7.66	1.06	8.07[c]	6.35
1971	77.3	-	-	89.5	7.30	1.02	7.87[c]	2.02
1972	~ 0	-	May 23	93.0	8.10	1.01	4.10[c]	-
Mean ± 1 S.D.	40.7±35.4	May 8±8	May 15±7	86.2±5.6	6.94±1.33 7.32±0.87[b]	1.10±0.08	5.11±2.09	1.59±1.76

[a] See Append. 45, 46 and 50 for details.
[b] Excluding 1962 brood year data (a possible artefact).
[c] Approximately 1,600 smolts, originating from the transplant of fry into Hunt's Creek, are included in these data.
[d] No egg deposition data since adults not counted or sampled.

River experimental hatchery were transplanted to Hunt's Creek during 1970 to 1972 in order to enhance the stock; Append. 51).

The number of coho smolts migrating from Hunt's Creek averaged 5,110 fish annually (range 600 - 8,070; Table 37). The impact of the hatchery fry transplants became apparent in the 1970 and 1971 brood migrations which produced the highest recorded smolt outputs of approximately 8,000 fish each (Table 37).

Mean (± 1 S.D.) 50% completion of fry and smolt downstream runs from Hunt's Creek occurred on May 8 ± 8 days and May 15 ± 7 days respectively (Table 37), or about a week earlier than the corresponding mean dates for Big Qualicum River coho juveniles (Table 36).

Coho juvenile size and age composition

Migrant coho smolts from Hunt's Creek averaged 86.2 mm (range 77.7 mm - 93.1 mm) and 7.3 g (range 6.2 g - 8.6 g); their condition coefficient averaged 1.10 (range 1.01 - 1.21) (Table 37). Hunt's Creek smolts were consistently smaller than those from Big Qualicum River (Table 36). Although weight sampling was limited to eight downstream runs, the size difference of 57% by weight between the two groups was undoubtedly real.

Among the Hunt's Creek coho smolt migrants sampled between 1964 and 1973, an average of 97.0% were age 1+, while the remainder were age 2+ (Table 34). This is similar to the age composition of the Big Qualicum River coho smolts (Table 36).

Coho egg-to-smolt survival

The annual egg-to-smolt survival of Hunt's Creek coho, based on actual egg deposition, averaged 1.59% (range 0.19% - 6.35%; Table 37). Survival estimates of seven broods available for both the main river and creek populations showed no consistent differences (Table 36). (This excluded the 1969 to 1971 creek broods to eliminate interference from transplanted coho fry.)

The wide variation in the annual egg-to-smolt survival of Hunt's Creek coho may be attributed in part to the high survival rates of the 1969 to 1971 broods. These rates were probably overestimated since corresponding production totals included smolts originating from the hatchery transplanted fry (survival estimates for the transplants, using mark recoveries, were inconclusive).

Marine catch distribution of Big Qualicum River coho

Marine migration patterns of coho juveniles from Big Qualicum River were determined using coded wire tag recoveries of the 1971 brood releases (Argue 1976). Big Qualicum River coho were recovered as far south as Coos Bay, Oregon, but the majority were found in Georgia Strait and coastal B.C. regions up to Prince Rupert, about 700 km northwest of the Big Qualicum River. By comparison, coho from Capilano River, situated across the Georgia Strait from Big Qualicum River, showed a greater tendency to remain in southern waters.

Marine survival of Big Qualicum River coho

Throughout most of the study period it was technically difficult to segregrate the Big Qualicum River coho from Hunt's Creek fish. As stated previously, smolts were not counted by source of origin prior to 1963. Also, returning adults which originated from Hunt's Creek may have entered the Big Qualicum River and were counted as river returns. Due to the above complications, all calculations for marine survival to escapement were made for the total system up to the 1968 brood. For the 1969 to 1972 broods, survival estimates were made only for the river populations.

The smolt-to-adult survival to escapement of Big Qualicum River coho averaged 10.8% (range 5.4% - 15.5%) for the 1958 to 1972 broods (Table 38). These data were adjusted for hatchery returns so that only wild fish are included in the results. By comparison, lower survival rates were observed in other areas: marine survival to escapement of coho smolts from Waddell Creek, California, averaged only 5.0% (range 1.0% - 7.7%) over four broods (Shapovalov and Taft 1954); survival of coho from Nile Creek, B.C., averaged 6.0% (range 3.2% - 9.9%) over three broods (Wickett 1951); and survival of coho from Minter Creek, Washington, averaged 3.8% (range 0.9% - 9.4%) over 10 broods (Salo and Bayliff 1958).

CHINOOK SALMON

Chinook salmon in Big Qualicum River

Table 38. Annual coho escapement by age, and marine survival to escapement of wild coho smolts from Big Qualicum River, 1958-1972 broods.

Brood year	Escapement to system at age			Escapement			No. wild coho smolts[a] (x 1000)	Marine survival of wild coho smolts to escapement[b] (%)
	2	3	4	Wild coho	Hatchery reared coho	Total		
1958	303	2,286	0	2,589	0	2,589	19.1	13.6
1959	600	4,220	0	4,820	0	4,820	31.1	15.5
1960	395	1,027[c]	0	1,422[c]	0	1,422[c]	26.1	5.4
1961	325[c]	4,869	0	5,194[c]	0	5,194[c]	33.7	15.4
1962	371	3,122	0	3,493	0	3,493	33.9	10.3
1963	699	4,335	0	5,034	0	5,034	35.8	14.1
1964	629	1,346	0	1,975	0	1,975	30.9	6.4
1965	302	2,381	0	2,683	0	2,683	29.3	9.2
1966	235	1,821	0	2,056	0	2,056	19.6	10.5
1967	345	3,085	41	3,471	0	3,471	38.2	9.1
1968	2,370	8,594	0	8,186-9,139	1,825-2,778	10,964	61.0	13.4-15.0[d]
1969	468	1,026	87	1,141-1,167	414-440	1,581	14.4	7.9-8.1[d]
1970	607	2,232	2,174	4,023	990	5,013	30.9	13.0
1971	3,121	13,336	0	7,008	9,449	16,457	64.3	10.9
1972	2,827	23,507	0	2,057	24,277	26,334	30.1	6.8
Mean ± 1 S.D.	-	-	-	-	-	-	-	10.8±3.3[e] 10.9±3.4[e]

[a] Includes Hunt's Creek coho up to the 1968 brood (but not for the 1969 and subsequent broods), those coho spawned in chum spawning channels, and smolts reared below hub 290; excludes hatchery coho (Append. 46).
[b] Excludes fishery exploitation.
[c] Incomplete.
[d] Ranges for 1968 and 1969 reflect uncertainty in mark recovery analyses (Fraser et al. unpublished MS).
[e] Using lower and upper ranges for 1968 and 1969 brood years.

Chinook escapement

During 1949 to 1958, prior to project development, annual chinook escapement to the Big Qualicum River averaged around 800 fish (Table 1). During 1959 to 1972, annual chinook escapement to the river system averaged 1,300 fish (range 600 - 2,400; Table 39). Jacks comprised approximately 28% of the overall escapement (Table 39). (Chinook escapement was divided into adult and jack components from 1964 onward; prior to 1964 only total counts were available).

Chinook adult migration timing, river life-span and spawning distribution

The overall mean dates (± 1 S.D.) for commencement, 50% completion and total completion of the chinook run into Big Qualicum River were August 31 (± 11 days), October 4 (± 12 days) and November 12 (± 16 days) respectively (Fig. 24, Table 40). The date of median escapement before flow control (October 7) was not significantly altered in post-flow control years (October 3; Table 41), and the earliest and latest 50% completion dates (September 8 and October 24) both occurred during the pre-flow control years (1962 and 1959 respectively). Mean (± 1 S.D.) duration of the run was 70 ± 15 days.

Diel timing of chinook migration into the Big Qualicum River was inconclusive due to insufficient data but the timing apparently varied considerably. On three sample dates in 1961, maximum fence counts were made in the evening, while on a single date in 1963, high counts occurred in the morning and afternoon. By comparison, Cowichan River chinook were observed to move upstream at dawn and dusk during the early part of the season, but in the afternoon during the later peak migration periods (Lister et al. 1971).

Death of spawned out Big Qualicum River chinook occurred approximately 18 days after leaving the sea. Chinook salmon migrated quickly to the river falls as indicated by the average 4.4 day period between peak migration past the fence and peak spawning ground count (range 4-5 days during six years). Peak spawning occurred 12.8 days later (range 10-14 days during five years). Subsequent die-off occurred within a day or two.

Chinook, like coho, were found throughout the river length but were most abundant upstream in section 1 (64% of total chinook spawners) where their density peaked at 518 fish/km of river length (Fig. 25, Table 9). Chinook usually swam directly upstream to the large pool at the base of the impassable fourth falls, held there for 10 to 14 days, then dropped back to spawn largely within the upper 3 km of the river.

Chinook adult age, length and sex composition

Most chinook returns to the Big Qualicum River were age 3 (28.1%) and 4 (48.6%), but age 2 chinook were also common (21.2%) and some age 5 fish (2.1%), mostly females, were usually present (Table 40). The two-year old male jacks were always present and occasionally outnumbered the larger fish, as in 1968 (Table 40).

Pritchard (1940) examined 2,834 troll-caught chinook from the B.C.coast and reported the occurrence of ages 2 to 7 with some possible occurrence of ages 8 and 9. Ginetz (1976) reported that Skeena and Nass River stocks in northern B.C. were predominantly age 4 with a range of 2 to 6 years. Junge and Phinney (1963) reported that fall chinook in Columbia River were 2 to 5 years old with occassional occurrence of older fish.

The length of 2, 3, 4 and 5-year old chinook averaged 479 mm, 697 mm, 802 mm and 831 mm respectively and tended to increase with age (Table 40). Males and females of equal age had similar lengths (Table 42).

Females comprised on the average 45.3% (range 25.7% - 60.8%) of the chinook spawners; female component, excluding jacks, averaged 54.9% (range 42.9% - 70.1%; Table 40). By comparison, the overall female composition of chinook from other systems in B.C. was as follows: Skeena and Nass Rivers (34%; Ginetz 1976); Nechako, Quesnel and Horsefly Rivers (52%, 45% and 63% respectively; Olmsted et al. 1980); Nitinat River (49%; McCart et al. 1980); and Eagle and Salmon Rivers (55% and 64% respectively; Whelen and Olmsted 1982).

Sex composition of Big Qualicum River chinook varied significantly among age classes ($p < 0.01$); females predominated in age classes 4 and 5, while all jacks and most age 3 chinook were males (Table 43). Similar observations were made for Nitinat River chinook (McCart et al. 1980), and Salmon and Adams River chinook (Whelen and Olmsted 1982).

Table 39. Annual chinook escapement to Big Qualicum River system, 1959-1972.

Year	River above hub 290			River below hub 290			Spawning channels or holding pond[a]			System		
	Adults	Jacks	Total	Adults	Jacks	Total	Adults	Jacks	Total	Adults	Jacks	Total
1959	-	-	2,399	-	-	12[b]	-	-	-	-	-	2,411
1960	-	-	1,512	-	-	58[b]	-	-	-	-	-	1,570
1961	-	-	1,087	-	-	24[b]	-	-	-	-	-	1,111
1962	-	-	787	-	-	10[c]	-	-	-	-	-	797
1963	-	-	621	-	-	15[c]	-	-	-	-	-	636
1964	583	119	702	10	-	10[d]	70	31	101	663	150	813
1965	1,118	137	1,255	10	-	10[d]	-	-	-	1,128	137	1,265
1966	870	300	1,170	10	-	10[d]	-	-	-	880	300	1,180
1967	503	95	598	10	-	10[d]	261	18	279	774	113	887
1968	262	723	985	20	-	20[c]	287	50	337	569	773	1,342
1969	1,272	796	2,068	10	-	10[d]	182	143	325	1,464	939	2,403
1970	633	553	1,186	10	-	10[d]	426	48	474	1,069	601	1,670
1971	706	277	983	10	-	10[d]	438	3	441	1,154	280	1,434
1972	312	79	391	10	-	10[d]	533	-	533	855	79	934
Mean	695	342	1,125	-	-	-	-	-	-	951	375	1,318

[a] 1964 Channel No. 1;
1967-72 fish held for hatchery stock.
[b] Estimated by project biologists.
[c] Estimated from distribution counts.
[d] Minimum estimate based on observations in other years.

Table 40. Chinook adult migration timing, brood stock characteristics and egg deposition in Big Qualicum River, 1959-1972 broods.[a]

Brood year	Date of 50% river migration	Females (%)		Age composition (%)				Length (mm) at age				Mean fecundity	Egg retention (%)	No. females (eggs/female)	Actual egg deposition (millions)
		Total escapement	Excluding jacks	2	3	4	5	2	3	4	5				
1959	Oct. 24	51.7	-	19.5	25.0	47.2	8.3	538	638	839	862	5,679	11.0[b]	1,240	6.27
1960	Oct. 13	52.6	-	6.8	8.1	83.8	1.3	516	738	862	845	5,989	13.0	795	4.13
1961	Oct. 13	36.0	-	29.6	40.7	28.8	0.9	503	724	850	805	5,552	11.0[b]	391	1.93
1962	Sept. 8	60.8	-	9.9	28.1	60.3	1.7	550	741	859	895	5,833	13.4	478	2.42
1963	Oct. 13	57.8	-	3.2	9.5	84.1	3.2	500	793	849	917	5,951	9.8	359	1.93
1964	Oct. 8	36.4	55.3	28.0	48.0	24.0	0.0	515	716	843	-	5,434	11.0[b]	267	1.29
1965	Oct. 4	53.5	60.0	9.4	40.9	49.3	0.4	530	744	828	860	5,570	2.6	671	3.64
1966	Oct. 6	52.1	70.1	17.9	19.4	59.7	3.0	459	696	776	833	5,298	2.0	610	3.17
1967	Oct. 7	44.8	50.7	12.7	49.5	35.4	2.4	435	658	761	807	4,908	11.0[b]	255	1.11
1968	Oct. 9	26.9	65.3	57.6	8.5	33.9	0.0	464	674	754	-	5,108	11.0[b]	171	0.78
1969	-[c]	25.7	45.4	39.1	45.8	14.0	1.1	432	658	753	797	4,799	17.1	577	2.30
1970	Sept. 23	34.9	45.5	36.0	14.0	49.1	0.9	407	682	765	797	4,680	30.3	288	0.94
1971	Sept. 27	48.3	58.7	18.5	35.0	43.5	3.0	380	644	745	789	5,398	11.0[b]	427	2.05
1972	Sept. 21	42.2	42.9	8.6	21.1	67.4	2.9	-	646	746	788	5,044	0.2	134	0.67
Mean ± 1 S.D.	Oct. 4±12	45.3±11.1	54.9±9.5	21.2±15.3	28.1±15.2	48.6±21.0	2.1±2.1	479±54	697±47	802±48	831±46	5373±419	11.0±9.9	-	2.33±1.50

[a] See Append. 52-57 for details.
[b] Mean of other years.
[c] Not available since most of adult migration completed that year prior to start of fence operation on October 17.

Table 41. Comparison of biological parameters for chinook salmon in Big Qualicum River before and after flow control, 1959-1972 broods.

Parameter	Before flow control		After flow control		Wilcoxon's U-Statistic[a]	
	No. broods	Mean ± 1 S.D.	No. broods	Mean ± 1 S.D.		
Adult escapement						
- 50% completion	4	Oct 7±20	9	Oct. 3±8	26	n.s.
Egg retention (%)	2	13.2±0.3	6	10.3±11.6	8	n.s.
Egg incubation						
- mean temperature (°C)	4	7.3±0.9	9	6.1±0.5	33.5	**
- duration (days)	4	167±16	9	177±20	21	n.s.
- thermal units (°C-days)	4	1219±126	9	1069±138	29	n.s.
Migrant fry						
- 50% migration	4	Apr. 8±17	9	Apr. 10±21	24	n.s.
- length (mm)	2	45.1±1.1	9	43.1+1.4	17	n.s.
- number produced[b]	4	46,400±43,900	10	120,000±89,400	31	n.s.
Migrant fingerlings						
- 50% migration	4	June 2±1	10	June 17±12	40	**
- length (mm)	4	73.7±13.0	10	72.3±2.7	27	n.s.
- weight (g)	2	3.29±0.68	10	4.07±0.46	17	n.s.
- condition (mg/mm^3)	2	1.066±0.014	10	1.038±0.041	16	n.s.
- number produced[b]	4	55,600±41,400	10	60,900±36,800	21	n.s.
Egg-to-fingerling survival(%)	4	2.13±2.01	10	4.72±4.65	30	n.s.
Fingerling-to-adult escapement survival (%)	4	3.05±2.90	10	1.67±1.68	31.5	n.s.

[a] n.s. $p > 0.05$
** $p < 0.01$

[b] Production totals represent system above hub 290.

Table 42. Length of Big Qualicum River chinook by sex and age, 1959-1972 escapement average (± 1 S.D.).[a]

Age	Male	Female	Both sexes
2	479±54	-	479±54
3	693±54	712±98	697±47
4	802±56	802±45	802±48
5	819±44	835±47	831±46

[a] See Append 54-56 for details.

Table 43. Sex composition of Big Qualicum River chinook at different ages, 1959-1972 escapement average (± 1 S.D.).[a]

Age	Male(%)	Female(%)	Both sexes(%)
2	21.2±15.3	0.0	21.2
3	19.8±11.0	8.3±5.0	28.1
4	13.5±8.7	35.1±14.7	48.6
5	0.2±0.4	1.9±2.1	2.1
Total	54.7	45.3	100.0

[a] See Append. 53 for details.

Chinook fecundity, egg retention, and deposition

Chinook females were sampled for fecundity during seven years of the 1960 to 1972 study period (Append. 58). Since the length-fecundity correlation coefficients were insignificant for all except the 1970 and 1971 samples, an overall regression based on accumulated data was used in years other than 1970 and 1971. The linear correlation between fecundity and length in chinook was generally lower than that found for chum and coho (Append. 19 and 43), and even in the chinook sample with the highest correlation (1970) it explained only 14% of the variation between these two parameters. This poor correlation may be due in part to partial egg loss prior to egg counts.

Annual chinook fecundity at the Big Qualicum River averaged 5,373 eggs (range 4,680 - 5,969; Table 40). This is the middle range of fecundities reported for the Fraser River tributaries (3,000 - 6,500 eggs; Fraser et al. 1982), and low range compared to fecundities for Nass and Skeena River chinook (6,343 - 6,490 eggs for red chinook; and 7,298 - 9,109 eggs for white chinook; Ginetz 1976). Lower mean fecundities of 3,753 eggs were reported for Klamath River chinook (Wales and Coats 1965) and 3,885 eggs for Cowichan River chinook (Foerster and Pritchard 1936), and a similar fecundity of 5,090 eggs was reported for Columbia River chinook (Galbraith and Ridenhour 1964).

Chinook egg retention in Big Qualicum River averaged 11.0% (range 0.2% - 30.3%; Table 40). Egg retention was not significantly different before and after flow control (13.2% vs 10.3% respectively; Table 41) and retention rates of chum, coho and chinook were not correlated in the coincident years of observation (Tables 10, 31 and 40).

The estimated actual egg deposition in the river above the fence averaged 2.33 million eggs per year (range 0.67 million - 6.27 million; Table 40). Pre-flow control annual mean deposition (3.69 million eggs) was about twice as high as that in later years (1.79 million eggs). This corresponded to a decrease in the annual number of annual female spawners from approximately 726 fish during 1959 to 1962 to 376 fish during 1963 to 1973 when some females were used for hatchery stock (Table 40).

Chinook egg incubation

The incubation period of chinook was calculated as for chum and coho, from median spawning date (17 days after peak adult migration past hub 290) until the median date of emergent fry migration past hub 290. Chinook eggs incubated from October to May for an average of 174 days (range 148 - 204 days); temperatures during this period averaged 6.5°C (range 5.1°C - 8.3°C); and A.T.U's averaged 1115°C-days (range of 898 - 1394°C-days) (Fig. 24, Table 44). After flow control, when the mean incubation temperature dropped from 7.3°C to 6.1°C, the A.T.U. requirements declined from 1219 to 1069°C-days, and the length of incubation period increased from 167 to 177 days (Table 41). The above pre- and post-flow control differences in required A.T.U.'s and length of incubation period were not significant ($p > 0.05$).

Chinook juvenile numbers and migration timing

Chinook fry production in the river was not determined but the numbers moving downstream past hub 290 were monitored each spring. The number of fry migrants averaged 99,000 annually (range 3,000 - 297,000; Table 44). The number of fingerling migrants above hub 290 averaged 59,400 annually (range 4,600 - 131,000); their number below hub 290 averaged 4,700 annually (range 400 - 10,400) (Table 45). The latter was calculated as for coho smolts, by assuming that rearing capacity per unit river length was the same above and below the fence. The above extreme variability in the annual numbers of fry and fingerling migrants did not appear to be related to flow control (Table 41).

Chinook fry and fingerlings migrated between March and July at discrete times (Fig. 24); if overlap in timing occurred, the two groups were easily distinguished by size. Mean (± 1 S.D.) fry migration (1959-1972 broods) began on March 6 ± 11 days, reached 50% completion on April 10 ± 19 days, and ended on May 15 ± 12 days; mean duration of fry run was 71 ± 15 days (Fig. 24, Table 44). Mean (±1 S.D.) fingerling migration began on May 19 ± 10 days, reached 50% completion on June 12 ± 12 days, and ended on July 13 ± 19 days; mean duration of fingerling run was 56 ± 13 days (Fig. 24, Table 45).

Average mid-timing of fry was similar before and after flow control, but mid-timing of fingerlings was delayed significantly ($p < 0.01$) after flow control (June 17 vs June 2; Table 41). A similar significant delay in mid-timing

Table 44. Chinook egg incubation, fry enumeration and sampling in Big Qualicum River, 1959-1972 broods.[a]

Brood year	Mean incubation temperature (°C)	Incubation period (days)	Accumulated thermal units (°C-days)	Date of 50% migration	Migrant Fry: Mean length (mm)	Migrant Fry: Mean weight (mg)	Migrant Fry: Condition coefficient	No. fry (x1000)
1959	7.0	160	1120	Apr.18	-	-	-	107.0
1960	8.3	148	1228	Mar.26	45.9	-	-	3.0
1961	6.3	180	1134	Apr.27	44.3	-	-	31.5
1962	7.7	181	1394	Mar.24	-	-	-	44.1
1963	6.7	158	1059	Apr. 5	-	-	-	297.0
1964	6.3	203	1279	May 15	43.3	650	0.77	50.7
1965	6.7	157	1052	Mar.26	42.4	570	0.75	202.0
1966	6.2	164	1017	Apr. 4	44.2	670	0.76	152.0
1967[b]	5.8	158	916	Mar.30	41.5	510	0.71	19.2
1968[b]	5.1	176	898	Apr.19	42.5	600	0.76	190.0
1969[b],[c]	-	-	-	Mar.10	41.7	570	0.77	91.5
1970	6.1	201	1226	Apr.28	45.8	690	0.80	43.4
1971	5.9	204	1204	May 5	44.0	680	0.74	114.0
1972	5.7	170	969	Mar.26	42.5	620	0.77	40.4
Mean ± 1 S.D.	6.5±0.9	174±19	1115±148	Apr.10±19	43.5±1.5	618±61	0.76±0.02	99.0±84.7

[a] See Append. 59 and 60 for details.
[b] Approximately 87,000 migrant fry from 1967-1969 broods were held for freshwater rearing (Append. 60).
[c] Incubation parameters not calculated since median date of upstream adult migration not known.

Table 45. Chinook fingerling enumeration and sampling, and egg-to-fingerling survival in Big Qualicum River, 1959–1972 broods.[a]

Brood year	Date of 50% migration	Migrant fingerlings: Mean length (mm)	Migrant fingerlings: Mean weight (g)	Migrant fingerlings: Condition coefficient	No. fingerlings (x1000): Above hub 290[b]	No. fingerlings (x1000): Below hub 290	Egg-to-fingerling survival (%)[c]
1959	May 31	93.0	-	-	49.4	3.9	0.79
1960	June 1	67.9	-	-	4.6	0.4	0.11
1961	June 2	64.4	2.81	1.06	63.3	5.0	3.28
1962	June 3	69.6	3.77	1.08	105.0	8.3	4.35
1963	June19	76.3	4.83	1.06	38.1	3.0	1.98
1964	June14	73.6	4.10	1.03	69.9	5.6	5.41
1965	June10	67.8	3.40	0.96	48.0	3.8	1.32
1966	June 9	71.5	3.86	1.02	40.5	3.2	1.28
1967	June12	74.5	4.35	1.04	19.6	1.6	1.76
1968	July 4	75.0	4.59	1.06	131.0	10.4	16.85
1969	June 6	72.5	4.18	1.00	61.0	4.9	2.66
1970	July10	70.6	3.76	1.03	45.3	3.6	4.82
1971	June14	68.7	3.44	1.11	120.0	9.5	5.85
1972	June 7	72.7	4.16	1.07	35.3	2.8	5.23
Mean ± 1 S.D.	June 12±12	72.7±6.7	3.94±0.56	1.04±0.04	59.4±36.6	4.7±2.9	3.98±4.17

[a] See Append. 59 and 61 for sampling details.
[b] Excluding fingerlings reared in the hatchery but including those reared in spawning channels; these are minimum estimates since some river fry migrating past hub 290 rear in the lower river.
[c] Calculated for fingerlings above hub 290.

of juvenile run after flow control was observed for chum fry (Table 8), but not for coho fry or smolts (Table 32).

The rearing period (± 1 S.D.) of chinook was estimated at 99 + 17 days. This was based on an assumption that the early emergent fry most successfully established rearing territories so that the rearing period could potentially extend from start of fry migration (March 6) to 50% completion of fingerling migration (June 12). The lower limit for rearing duration (± 1 S.D.) was estimated at 63 ± 18 days and was calculated as the time between median fry and fingerling migrations (April 10 - June 12).

Chinook fry migrations began shortly after dark, reached a peak about midnight and dropped off by morning. Similarly, chinook fingerlings moved primarily at night. Reimers (1973) also found that chinook fry from the Sixes River, Oregon, migrated at night and that light retarded the movement. He suggested that this may be a mechanism to ensure dispersal of juveniles to rearing areas.

Chinook juvenile size

Migrant chinook fry averaged 43.5 mm (range 41.7 mm - 45.8 mm) and 618 mg (range 510 mg - 690 mg); their condition coefficient averaged 0.76 (range 0.71 - 0.80) (Table 44). Fry length was similar before and after flow control (Table 41). Migrant chinook fingerlings averaged 72.7 mm (range 64.4 mm - 93.0 mm) and 3.94 g (range 2.81 g - 4.83 g); their condition coefficient averaged 1.04 (range 0.96 - 1.11) (Table 45). Fingerling size did not differ significantly before and after flow control (Table 41). However, if the exceptionally large fingerlings from 1959 brood (Table 45) are excluded from the analysis, the mean length after flow control would be 7% greater than before flow control (72.3 mm vs 67.3 mm) ($p < 0.05$).

Juvenile chinook sampled during the migratory period showed a definite shift with time from fry to fingerling size; a similar shift was observed in the condition coefficient (Fig. 36). Lister et al. (1971) also reported that among chinook juveniles in Cowichan River, B.C., an early group of emergent fry migrated in March and April, followed by a later group of reared fingerlings in May and June.

A positive correlation ($r = 0.73$, 8 d.f.) was found between fry length and A.T.U.'s. No correlation was found between fingerling length and mean rearing temperature, minimum flows during the rearing period, female brood stock length, time period between 50% accumulation of fry and fingerling outmigrations, or numbers of migrant fingerlings. The highest mean rearing temperature (9.7°C) was recorded in 1960 for the 1959 brood which produced the largest fingerlings, but temperature means ranged from 6.3°C to 9.4°C in other years and had no apparent predictable effect on juvenile size.

Chinook egg-to-fingerling survival

The annual egg-to-fingerling survival of Big Qualicum River chinook, based on actual egg deposition, averaged 3.98% (range 0.11% - 16.86%; Table 45). No significant difference was observed in the Big Qualicum River pre- and post-flow control survival rates (Table 41).

Marine catch distribution of Big Qualicum River chinook

Big Qualicum River chinook have a more northerly distribution pattern than coho salmon. Recoveries of nose tagged 1971 brood chinook were made along the B.C. coast and in the Alaska troll fisheries; none were recovered in the U.S. fisheries to the south (Argue 1976).

Marine survival of Big Qualicum River chinook

In order to estimate marine survival, chinook returns to the Big Qualicum River were assigned to appropriate brood year and adjusted for hatchery returns (1967-1972 broods) (Table 46).

The fingerling-to-adult survival to escapement of wild (river and channel) Big Qualicum River chinook averaged 2.04% (range 0.42% - 7.36%; Table 46). By comparison, hatchery-produced fingerlings were very unsuccessful; escapement survivals of nine release groups of the 1967, 1968, 1970 and 1971 broods ranged from 0% to 0.67% (Fraser et al. unpublished MS). More recent returns to B.C. hatcheries indicate that marine survival, including catch, of artificially reared chinook is approximately 3%.

STEELHEAD TROUT

Steelhead trout in Big Qualicum River were least abundant and were studied less intensively compared to chum, coho and chinook. However,

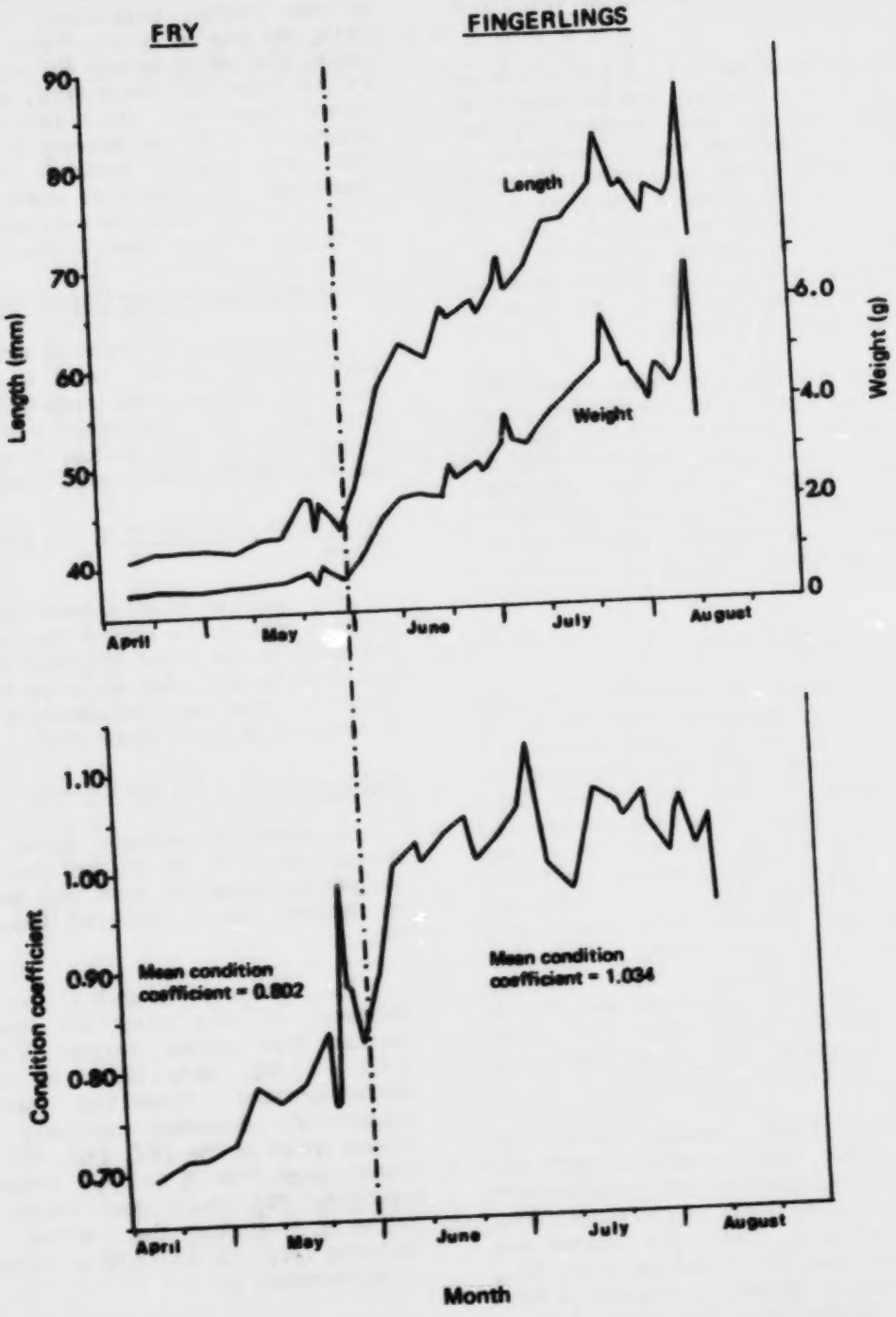


Fig. 36. Mean length, weight and condition coefficient of juvenile chinook migrating from Big Qualicum River, April – August 1971.

Table 46. Annual chinook escapement by age, and marine survival to escapement of wild and total chinook fingerlings from Big Qualicum River system, 1959-1972 broods.

Brood year	Escapement to system at age[a]				Escapement			No. fingerlings (x1000)[c]			Marine survival to escapement[d] (%)	
	2	3	4	5	Wild chinook	Hatchery reared chinook[b]	Total	Wild	Hatchery	Total	Of wild fingerlings	Of total fingerlings
1959	329	224	535	0	1,088	0	1,088	53.3	0	53.3	2.04	2.04
1960	79	61	221	5	366	0	366	5.0	0	5.0	7.36	7.36
1961	20	441	614	32	1,107	0	1,107	68.3	0	68.3	1.62	1.62
1962	150	510	640	21	1,321	0	1,321	113.0	0	113.0	1.17	1.17
1963	137	208	314	0	659	0	659	41.5	0	41.5	1.59	1.59
1964	300	439	455	26	1,220	0	1,220	81.2	0	81.2	1.50	1.50
1965	113	114	337	15	579	0	579	51.8	0	51.8	1.12	1.12
1966	773	1101	820	42	2,736	0	2,736	43.7	0	43.7	6.26	6.26
1967	939	234	616	27	346	1,470	1,816	21.8	251.0	272.8	1.59	0.67
1968	601	496	630	50	1,750	27	1,777	142.0	306.5	448.5	1.23	0.40
1969	280	197	566	25	1,068	0	1,068	65.9	8.8	74.7	1.62	1.43
1970	79	27	93	17	82	134	216	48.9	88.2	137.1	0.17	0.16
1971	641	445	1049	48	1,154	1,029	2,183	129.0	166.0	295.0	0.89	0.74
1972	211	249	527	114	159	942	1,101	38.1	517.0	555.1	0.42	0.20
Mean ± 1 S.D.	-	-	-	-	-	-	-	-	-	-	2.04±2.09	1.88±2.18

[a] See Append. 62 for division of escapement by age; includes hatchery incubated and reared fish, and river fry reared to migrant fingerling stage.
[b] Returns of these stocks were estimated by mark return analysis (Fraser et al. unpublished MS).
[c] See Append. 61.
[d] Excludes fishery exploitation.

they are important due to their attraction to anglers and the extended rearing period during which they prey upon juvenile salmon.

Steelhead escapement and migration timing

During 1964/65 to 1972/73, annual steelhead return averaged 618 fish (range 366 - 788) of which 31% to 47% were caught by anglers (Table 47). More steelhead were caught below the fence than above, reflecting the ease of access to downstream section of the river and possibly some concentration of fish in lower reaches due to fence obstruction. A few steelhead may have spawned in the lower reaches but it is believed that fence counts plus catch below the fence closely approximated the total escapement.

Escapement totals from 1964/65 to 1969/70 included those fish trapped at the original mouth of Hunt's Creek then transported over the dyke and placed in the tributary. No estimate of the spawning population in the creek was made since 1970 when the flood channel became accessible. As a result, the system totals since 1970 may be slightly underestimated.

The overall mean dates (± 1 S.D.) for commencement (1969/60 to 1972/73 data), 50% completion and total completion (1964/65 to 1972/73 data) of steelhead run into the Big Qualicum River were November 12, ± 12 days, January 26 ± 11 days and April 10 ± 20 days respectively; mean duration of the run was 156 ± 33 days (Fig. 24).

Steelhead adult age, length and sex composition

Most steelhead returns to the Big Qualicum River during 1964/65 to 1966/67 were age 4_3 (58.3%) and 5_3 (24.9%) (Table 48). Age 4_3 adults returning in 1966/67 hatched in late spring or early summer of 1963; spent two winters and one summer in the river prior to migration during spring of 1965; reared in the ocean for two summers and one winter; then returned during the winter of 1966/67. Age 5_3 adults had a similar life history but with an additional year in salt water.

Age composition of different steelhead stocks is quite variable. Withler (1966) examined 1,660 adult steelhead caught in several southeastern B.C. streams and found 16 age classes ranging from 2_2 to 8_5. Most common were the 5_4 and 6_4 age groups. Narver and Withler (1971) examined 101 adult steelhead caught in several Vancouver Island streams and found eight age classes ranging from 3_2 to 6_5, the most common being 4_3, 5_3 and 5_4. Their results coincide with those at the Big Qualicum River. Shapovalov and Taft (1954) reported the presence of 12 age classes among early spawning steelhead in Waddell Creek, California. These fish ranged from age 2_2 to 7_5, but age 3_3, 4_3 and 4_4 fish were the most common. This is notable since the 3_3 and 4_4 age classes spend one growing season, but less than one calendar year, in salt water.

Steelhead trout may spawn repeatedly. They may spawn before leaving freshwater, after returning from saltwater, and after a second or even subsequent freshwater - saltwater cycle. In the Big Qualicum River repeat spawners constituted 11.7% of all steelhead examined (Table 48). By comparison, in Waddell Creek, California, repeat spawners constituted 17.2% of all steelhead examined (Shapovalov and Taft 1954).

Mean length of steelhead ranged from 653 mm for age 4_3 fish to 813 mm for age 6_3 fish and tended to increase with age (Table 49). However, within one overall age group the fish with a shorter freshwater history (and longer saltwater history) were usually considerably larger than fish which reared an extra year in freshwater. For example, age 5_3 adults were, on average, 16% longer than age 5_4 adults. (This relationship was not always evident for age 6 fish, probably because of small sample sizes).

Females comprised 49.6% and 56.9% of sports-caught Big Qualicum River steelhead during the 1965/66 and 1966/67 seasons respectively (Peterson and Lyons 1968). Only 20% of the 35 repeat spawners in the 1965/66 Big Qualicum River sample were males (Peterson and Lyons 1968).

Steelhead fecundity, egg retention and deposition

Mean fecundity of 40 Big Qualicum River steelhead females sampled during 1964/65 to 1966/69 averaged 3,866 eggs. No estimate of egg retention was obtained but it was probably lower than that for other salmonid species since fish densities were low during the period of steelhead spawning. Shapovalov and Taft (1954) examined five female carcasses and found that egg retention was very low (0-58 eggs). Egg retention has been seldom measured in steelhead trout because they do not die immediately after spawning.

Table 47. Annual steelhead upstream counts and sports catch in Big Qualicum River, 1959-1973.

Year	Fence count (hub 290)[a]	Catch				Total return[a]	No. spawning above fence
		Above fence	Below fence	Total No.	Total % of return		
1959/60	19[b]	-	-	-	-	-	-
1960/61	69[b]	-	-	-	-	-	-
1961/62	126[b]	-	-	-	-	-	-
1962/63	14[b]	-	-	-	-	-	-
1963/64	71[b]	-	-	-	-	-	-
1964/65	402	103	126	229	43	528	299
1965/66	405	84	204	288	47	609	321
1966/67	610	121	178	299	38	788	489
1967/68	440	103[c]	167[c]	270[d]	44	607	337
1968/69	540	99[c]	161[c]	260[d]	37	701	441
1969/70	408	57[c]	93[c]	150[d]	30	501	351
1970/71	513	100[c]	165[c]	265[d]	39	678	413
1971/72	590	118[c]	192[c]	310[d]	40	782	472
1972/73	288	47[c]	78[c]	125[d]	34	366	217[e]
Mean	-	92	152	244	39	618	371

[a] Incomplete count; see methods for explanation.
[b] Total return = fence count (includes above fence catch) + below fence catch.
[c] The total sports catch was assigned to location using the above to below fence catch ratio determined during Fish and Wildlife surveys (1964/65 - 1966/67), and data from Peterson and Lyons (1968).
[d] Estimated by project personnel.
[e] 24 fish were held for egg-take leaving 217 for natural spawning.

Table 48. Steelhead adult age composition and number of repeat spawners in Big Qualicum River, 1964-1967 (n gives sample size).

Age class	1964/65		1965/66		1966/67		Three year total	
	n	%	n	%	n	%	n	%
3_2	4	3.3	3	1.2	0	0.0	7	1.3
4_2	2	1.6	1	0.4	0	0.0	3	0.5
3_3	1	0.8	0	0.0	2	1.2	3	0.5
4_3	57	46.7	138	54.8	123	71.5	318	58.3
5_3	37	30.3	59	23.4	40	23.3	136	24.9
6_3	3	2.5	7	2.8	0	0.0	10	1.9
4_4	2	1.6	36	14.3	3	1.8	41	7.5
5_4	15	12.3	7	2.8	3	1.8	25	4.6
6_4	1	0.8	1	0.04	1	0.6	3	0.5
Total	122	100	252	100	172	100	546	100
Repeat spawners	25	20.0	35	14.0	4	2.3	64	11.7

[a] Sports caught fish were sampled for scales and assigned to one of nine age classes (Peterson and Lyons 1968).

Table 49. Steelhead adult fork length (mm) by age, Big Qualicum River, 1964-1967 (n gives sample size).

Year	Age Class 4_3		5_3		5_4		6_3		6_4	
	n	Length	n	Length	n	Length	n	Length	n	Length
1964/65	57	678	37	774	15	656	3	785	1	895
1965/66	138	637	59	748	36	647	7	841	7	754
1966/67	123	645	40	765	3	673	0	-	1	750
Mean ± 1 S.D.	-	653±22	-	762±13	-	659±13	-	813±40	-	800±83

Annual potential egg deposition, including Hunt's Creek up to 1969/70, averaged 731,000 eggs (range 421,000 - 1,060,000; Table 50).

Steelhead juvenile production and migration timing

Steelhead trout in the Big Qualicum River generally spawn from January to April (T. Kyte, DFO, pers. comm.). Fry emerge in late spring or early summer. At the Big Qualicum River, newly emerged steelhead fry were found in downstream traps in June and early July (Fig. 24) but the data on fry timing and abundance are incomplete since traps were removed at the end of salmon juvenile migrations. Steelhead smolts were the most intensively studied phase of this species' life cycle; their downstream counts were obtained from 1960 onward.

The annual number of wild steelhead smolts migrating out of the river system averaged 2,665 (range 641 - 4,688; Table 51). Hunt's Creek migrants generally accounted for about 5% of the system migrants. In 1974, however, 27% of the system smolts originated from this tributary (7,123 marked steelhead were transplanted from the hatchery to Hunt's Creek in 1974; only 383 of these fish migrated in 1974; creek migrants were not monitored in 1975). Hatchery releases into the river, initiated in 1973, exceeded wild production in 1973 and 1975 (Table 51).

Mean migration (± 1 S.D.) of steelhead smolts from Big Qualicum River (1960 - 1975 data) began on March 28 ± 20 days, reached 50% completion on May 22 ± 7 days and ended on June 20 ± 20 days; mean duration of the run was 85 days (Fig. 24, Table 51). Although the basic migration pattern was similar before and after flow control, the mean date (± 1 S.D.) for 50% completion of smolt migration was delayed considerably after flow control (May 25 ± 4 days vs. May 13 ± 7 days; Table 51). Similar delay in median migration dates after flow control was previously noted for chum fry and chinook fingerlings.

Steelhead juvenile size and age composition

Migrant steelhead smolts were on the average larger after flow control than before (179 mm, 60.5 g vs 144 mm, 35.5 g; Table 52). This size difference may have been partly due to improved rearing conditions in the Big Qualicum River after flow control, as well as increased trapping efficiency for larger fish. Limited data from 1963 and 1973 suggest that post-flow control steelhead smolts rearing in the river were also larger than smolts from Hunt's Creek; the river smolts were similar in length to the creek smolts in 1963 (163 mm vs 161 mm respectively), but were larger in 1973 (172 mm, 55.1 g vs 151 mm, 32.9 g) (Table 53).

A pulse of early migrating, large smolts was observed in the Big Qualicum River during 1966, 1970 and 1973 (Fig 37, 1966 data). (River smolts were sampled from April to June in 1960 to 1962, 1966, 1970 and 1973; in other years sampling was restricted to late May and June). By comparison during the pre-flow control period, early migrants were smaller than later migrants (Fig. 37, 1962 data) suggesting that either young smolts (age 1+) migrated before older smolts or that no age segregation occurred and increased size reflected growth during April and May. The apparently reversed situation after flow control may be the result of either delayed migration of small fish or early migration of large fish. Everest (1973) observed a pulse of early migrating larger smolts in Rogue River, Oregon.

Migrating smolts could not be assigned to brood year since the freshwater rearing period varied from one to three years and age data were obtained for only three downstream runs (Table 54). The limited data indicated a predominance of age 1+ (27.3% - 62.5% of the sample) and age 2+ (35.9% - 61.4% of the sample) smolts. Fish with three years of residency were less common (up to 11.3% of the sample).

A distinct "half-pounder" class of steelhead trout in Big Qualicum River was apparent from scale analysis of adults in 1967/68 to 1968/69. These were immature fish that left freshwater to spend a short time in saltwater (perhaps the estuary); returned to the river (where they are susceptible to anglers); then re-entered the sea, still as immature fish. Fish of the "half-pounder" class were present throughout the study period but their scarcity prohibits the analysis of their numbers and migration patterns. However, the occurrence of wild "half-pounders" in the river is probably low. From 1974 onward, large populations of "half-pounders" class were identified (by tags) as hatchery stock, and were most likely large parr which established themselves in the river after release as yearlings. Everest (1973) reported that the summer steelhead from Rogue River, Oregon, contained a similar class of fish. He noted that, compared to small smolts,

Table 50. Steelhead fecundity and egg deposition in Big Qualicum River above hub 290, 1964-1973.

Year	Total spawners	Females[a] (%)	No. females	Mean fecundity[b] (eggs/female)	Potential egg deposition
1964/65	299	50.0	150	3,866	580,000
1965/66	321	49.6	159	3,866	615,000
1966/67	489	55.9	273	3,866	1,060,000
1967/68	337	50.0	169	3,866	653,000
1968/69	441	50.0	221	3,866	854,000
1969/70	351	50.0	176	3,866	680,000
1970/71	413	50.0	207	3,866	800,000
1971/72	472	50.0	236	3,866	912,000
1972/73	217	50.0	109	3,866	421,000
Mean ± 1 S.D.	-	50.6	-	3,866	731,000±194,00

[a] Sex ratio in years other than 1965/66 and 1966/67 is estimated.
[b] Used mean fecundity obtained during 1964/65 to 1966/69.

Table 51. Steelhead smolt enumeration and migration timing in Big Qualicum River system, 1960-1975.

Year of migration	Big Qualicum River		Hunt's Creek	Total wild smolts	Hatchery reared smolts[c]	Total migrants	Date of 50% migration from river
	Above main fence[a]	Below main fence[b]					
1960	-	162	-[d]	2,159	0	2,159	May 15
1961	-	162	-[d]	2,690	0	2,690	May 12
1962	-	162	-[d]	2,340	0	2,340	May 4
1963	2,397	190	483	3,070	0	3,070	May 21
1964	3,626	288	198	4,425	0	4,425	May 25
1965	1,161	92	28	1,333	0	1,333	May 29
1966	3,956	314	98	4,469	0	4,469	May 22
1967	1,961	156	26	2,193	0	2,193	June 1
1968	2,855	227	61	3,231	0	3,231	May 22
1969	1,060	84	68	1,221	0	1,221	June 2
1970	1,022	81	166	1,436	0	1,436	May 20
1971	636	51	45	819	0	819	May 30
1972	571	45	16	641	0	641	May 22
1973	3,252	258	108	3,618	5,084	8,702	May 21
1974	3,125	0	1,177	4,302	1,219	5,521	May 26
1975	4,688	0	-	4,688[e]	9,688	14,376	May 23
Mean ± 1 S.D.	-	-	-	2,665±1,366	-	3,664±3,522	May 22±7

[a] Includes smolts from spawning channels; main fence was at hub 297 instead of hub 290 in 1974 and 1975.
[b] Below fence estimates assume rearing capacity is equal per unit length of river above and below hub 290; estimates for populations below fence in 1960 - 62 are based on mean of other years.
[c] Most hatchery smolts were released above hub 290. Mark recoveries during downstream sampling were used to estimate the number of migrants resulting from these releases. All smolts released below the fence are included as migrants. In 1974, 7,123 steelhead smolts were released into Hunt's Creek of which 383 migrated the same year.
[d] Included with Big Qualicum River above fence counts.
[e] Minimum since Hunt's Creek flood channel migrants were not enumerated.

Table 52. Steelhead smolt length, weight and condition coefficient before and after flow control in Big Qualicum River, 1960-1973 (n gives sample size.)

Year of downstream run	Mean length (n)	Mean length (mm)	Mean weight (n)	Mean weight (g)	Condition coefficent
1960	164	154	-	-	-
1961	76	121	21	37.08	1.157
1962	41	136	29	33.81	1.122
1963	39	163	-	-	-
Pre-flow control mean (± 1 S.D.)		144±19		35.45±2.31	1.140±0.025
1964	43	180	-	-	-
1965	26	193	26	74.72	1.042
1966	109	182	-	-	-
1967	92	172	-	-	-
1970	95	183	85	63.04	1.005
1971	25	169	25	49.27	1.020
1973	303	172	172	55.07	1.078
Post-flow control mean (± 1 S.D.)		179±8		60.53±11.02	1.036±0.032

Table 53. Comparison of migrant steelhead smolt size in Big Qualicum River and Hunt's Creek before (1963 downstream) and after (1973 downstream) flow control.

Year	Site	n	Fork length (mm) Mean (range)	Weight Mean (range)
1963	Big Qualicum R.	39	163 (151-232)	-
	Hunt's Creek	49	161 (125-198)	-
1973	Big Qualicum R.	303	172 (116-225)	55.1 (21.6-119.5)
	Hunt's Creek	48	151 (75-200)	32.9 (3.4-69.6)

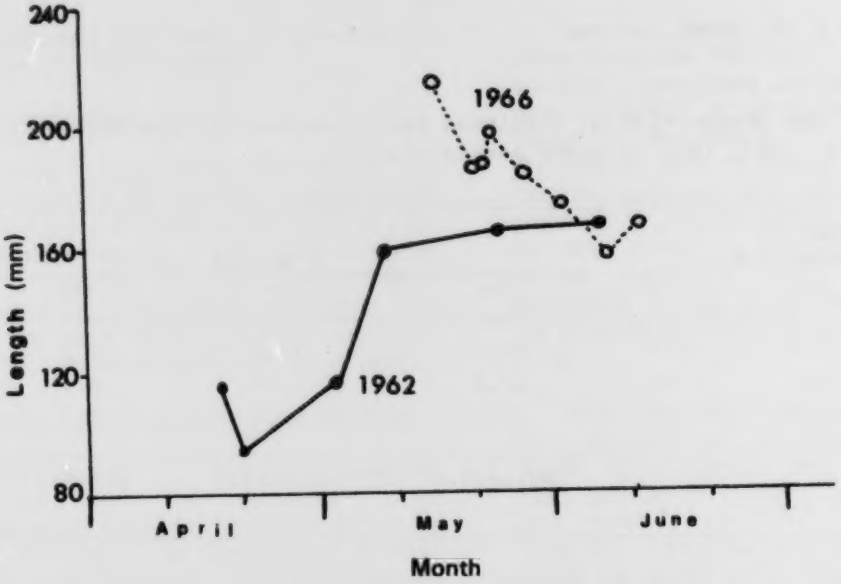


Fig. 37. Mean length of steelhead smolts migrating from Big Qualicum River during pre-flow (1962) and post-flow (1966) control periods.

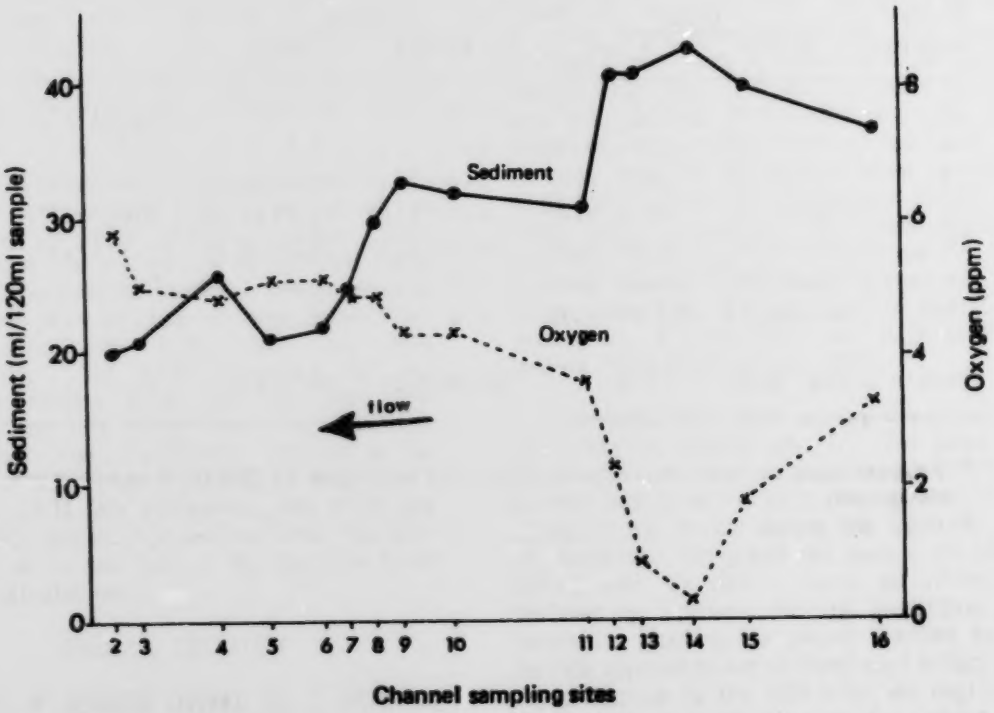


Fig. 38. Mean sediment and oxygen concentrations in spawning channel No.1, January – March 1966 (from: Giles MS 1967).

Table 54. Age composition of steelhead smolts migrating from Big Qualicum River, 1966, 1967, 1970 (n gives sample size).

Year of downstream run	n	% At age		
		1+	2+	3+
1966	75	62.5	37.5	0.0
1967	64	57.8	35.9	6.3
1970	44	27.3	61.4	11.3
Mean ± 1 S.D.	-	49.2±19.1	44.9±14.3	5.9±5.7

Table 55. Spawning distribution (% per river section) of chum, coho and chinook salmon in Big Qualicum River before (1959-1962) and after (1963-1972) flow control (± 1 S.D. is given in parenthesis).[a]

River section[b]	Chum		Coho		Chinook	
	Before	After	Before	After	Before	After
1	4.2(1.9)	2.5(1.7)	24.6(7.1)	41.7(34.4)	68.8(14.7)	72.7(12.2)
2	6.9(1.3)	5.9(5.0)	6.7(4.3)	8.5(8.4)	12.7(6.0)	19.1(6.8)
3	5.3(1.9)	5.4(4.9)	5.0(5.3)	11.8(15.3)	1.2(1.4)	5.2(3.3)
4	8.7(5.6)	4.7(3.2)	15.8(19.2)	14.1(11.9)	0.6(0.7)	0.6(1.1)
5	48.3(9.8)	50.0(12.9)	18.5(14.3)	6.9(8.3)	15.8(17.3)	1.9(3.1)
6	5.2(2.4)	5.3(2.0)	0.0	0.0	0.0	0.0
7	21.6(4.7)	26.2(7.8)	0.0	0.0	1.0(1.2)	1.3(2.2)
Hunt's Creek	0.0	0.0	29.6(9.2)	10.5(6.3)	0.0	0.0

[a] Proportions do not correspond exactly to those in Table 9 since they are not weighted.
[b] Fig. 25, Table 2.

large smolts were more likely to return during fall as immature "half-pounders".

Steelhead egg-to-smolt survival

The annual egg-to-smolt survival of Big Qualicum River steelhead was approximately 0.36%. This was calculated on the basis of mean annual potential egg deposition (731,000 during 1964/65 - 1972/73) and mean annual smolt downstream totals (2,662 during 1966-1975). The variable age structure of the smolt population did not permit calculation of survival by brood.

Marine survival of Big Qualicum River steelhead

Marine survival for individual steelhead broods could not be calculated since comprehensive age breakdown for smolts and adults was not available. An estimate of survival during the study period was calculated from mean annual smolt production and adult returns. Wild smolts migrating from 1960 to 1971 averaged 2,449 (Table 51). Annual adult escapement to the river during 1964/65 to 1972/73 averaged 618 fish including the local sports catch (Table 47) with commercial interceptions of the stock believed to be minor. Overall marine survival was therefore approximately 25%. This survival figure may be erroneous due to overestimates of the survival rate because of repeat spawning of steelhead; underestimates of migrant smolts; and underestimates of the returns, particularly since the 1970 opening of the Hunt's Creek flood channel for adult migration.

The estimated marine survival rate of Big Qualicum River steelhead (25%) is well above the rates cited in other studies. Wagner (1967) reported that the average marine survival rates for 35 hatchery-reared steelhead groups released during seven years of study in three Oregon river systems were only 1.9%, 2.5% and 5.0% respectively. The maximum survival for any particular release group was less than 10%. Shapovalov and Taft (1954) found that steelhead from Waddell Creek, California, survived at sea at rates of 2.4% (age 1 migrants), 5.8% (age 2 migrants), 18.1% (age 3 migrants), and 16.7% (age 4 migrants); migrant fry were excluded from this analysis, as in the case of Big Qualicum River survival calculations .

BIOLOGICAL EVALUATION

ASSESSMENT OF SPAWNING CHANNEL NO. 1 OPERATION AND PRODUCTION (OR WHAT WENT WRONG?)

Spawning channel No. 1 failed as a chum salmon production facility. High egg retention and poor, inconsistent survival from egg-to-fry were symptomatic of an inadequate spawning and incubation environment. The 1966 spawner distribution study in channel No. 1 showed that the combination of water velocities and depths preferred by spawning chum was rarely encountered in that channel. Suboptimal velocities or related conditions were apparently most detrimental to the larger females which showed the greatest egg retention according to the 1966 study.

Mortality among incubating eggs in channel No. 1 was most likely directly related to lack of oxygen due to extensive sedimentation. Sediment loads and oxygen concentrations in the gravel were inversely correlated in the test grids (Fig. 38). Conditions were worst at the upstream end of the channel where oxygen levels approached zero and egg-to-fry survival was very low. For example, upstream sections (12 to 17, Fig. 17) had only a 2.4% survival rate for the 1966 brood compared to 35.8% for the entire channel.

Extensive sedimentation in channel No. 1 was also probably responsible for the low egg-to-fry survival (39%) of pink salmon eggs transplanted into channel No. 1 in 1963 and 1964. By comparison, egg survival of pink salmon was 46.1% at Jones Creek spawning channel (MacKinnon et al. 1961), and 90.8% at Robertson Creek spawning channel (Boyd 1964). Higher freshwater survivals were also observed in the Upper and Lower Seton Creek spawning channels which had mean pink survival rates of 52.8% over seven broods and 55.5% over four broods respectively (IPSFC 1971, 1972, 1974). Somewhat lower mean egg-to-fry survivals were observed for sockeye in three spawning channels in the Babine system: 47.7% at Fulton channel No. 1 (1966-1975); 44.2% at Fulton channel No. 2 (1969-1975); and 36.8% at Pinkut channel (1968-1975) (Ginetz 1977).

Attempts were made to improve incubation conditions in channel No. 1. The banks were lined with corrugated asbestos board in 1965 to prevent bank spawning which had resulted in some damage to the channel during the first two years of operation. The gravel was removed and cleaned during 1965 to 1967. These activities were followed by improved, but not exceptional, egg survival. Doubling the channel gradient to 0.2% in 1968 apparently had no beneficial effect since fry production by the 1969 brood was negligible. It is likely that the addition of a tapered layer

of gravel had no effect on the slope of the base material which greatly influences water velocity.

Channel No. 1 fry sizes and marine survival rates were similar to the values for the river fry indicating comparable fry quality at release. Adult returns from channel No. 1 (1963 to 1967 broods) totalled about 40,000 chum and accounted for 5% of the system returns during that period (Table 26). While this contribution was below the expected total, the experience acquired during the operation of channel No. 1 was invaluable for the design of channel No. 2. In the spring of 1969, spawning channel No. 1 was converted into a juvenile rearing facility, and in 1970 the depth of the lower half was increased to 90 cm to expand its rearing potential. Since then, channel No. 1 has been used to raise hatchery-incubated chinook, coho and steelhead.

ASSESSMENT OF SPAWNING CHANNEL NO. 2 OPERATION AND PRODUCTION (OR WHAT WENT RIGHT?)

Spawning channel No. 2 succeeded as a chum salmon producing facility. Channel No. 2 mean egg survival for the 1967 to 1972 broods (74.5%) was much higher than that for the concurrent river broods (24.9%; Table 21) and for channel No. 1, 1963 to 1969 broods (32.9%; Table 19). It was also higher than the survival of chum eggs in Jones Creek spawning channel for those broods monitored between 1955 and 1971 (29.4%; Fraser et al. 1983), and the survival of pink and sockeye salmon in spawning channels at several other locations in B.C. (see assessment of spawning channel No. 1). Survival, similar to that achieved in channel No. 2, was recorded for chum eggs at the Abernathy channel in Washington where water-hardened green eggs and prewater-hardened green eggs survived at rates of 87.8% and 71.9% respectively (Thomas and Shelton 1968).

During the first four years of channel No. 2 operation, chum egg survival declined from 90.1% in 1967/68 to 60.6% in 1970/71 (Fig. 39, Table 23). This probably resulted from a combination of factors including increase in spawner density and sediment accumulation, as suggested by the fact that the highest egg survival (1967 brood, Table 23) occurred at lowest spawner abundance (Table 6) and prior to sedimentation (flow in channel No. 2 started on November 4, 1967, only two weeks prior to chum adult entry). Freshwater survival increased since 1970 to around 70% (Table 23).

The strong negative relationship between channel No. 2 egg survival and spawner density (Fig. 40) indicates that some of the egg mortality observed was probably due to the superimposition of redds. However, at a given spawner density, egg survival in channel No. 2 was several times higher than in the river (Fig. 40), indicating that other factors in the channel greatly favoured the egg-to-fry survival.

Maximum fry production per unit area in channel No. 2 was compared to the corresponding egg density in that channel (Fig. 41). These values were related to similar data for the Big Qualicum River (Fig. 42) and for seven other pink and chum producing locations reviewed by Bakkala (1970):

	Egg density (No. eggs/m^2)	Maximum fry production No. fry/m^2
Spawning channel No. 2	1,700 - 2,300	1,200 - 1,600
Big Qualicum River	1,000 - 1,200	350 - 450
Other locations (Bakkala 1970)	2,000 - 3,000	400 - 550

Compared to the ranges observed by Bakkala (1970), channel No. 2 had a much higher potential fry output per unit area at comparable saturation levels of egg deposition, while the Big Qualicum River had a similar potential fry output per unit area but at lower saturation levels of egg deposition.

Channel No. 2 fry sizes, swim stamina and marine survival rates were similar to the values for the river fry, indicating comparable fry quality at release. Fry production from channel No. 2 totalled 111 million for the 1967 to 1972 broods compared to 169 million for the Big Qualicum River, including areas above and below the counting fence at hub 290 (Append. 22). Thus, while the channel received only 16% of the total chum salmon egg deposition, it accounted for 40% of the system fry production. Adult returns from channel No. 2 (1967 to 1972 broods) totalled about 478,000 chum and accounted for 38% of the system returns during that period (Table 26).

Major modifications in the design of channel No. 2, based on experience with channel No. 1, were an increased gradient with higher water velocities, and a settling basin for silt at the channel inlet. The increased gradient was sufficient to ensure spawning flows of approximately 45 cm/sec to 100 cm/sec at depths

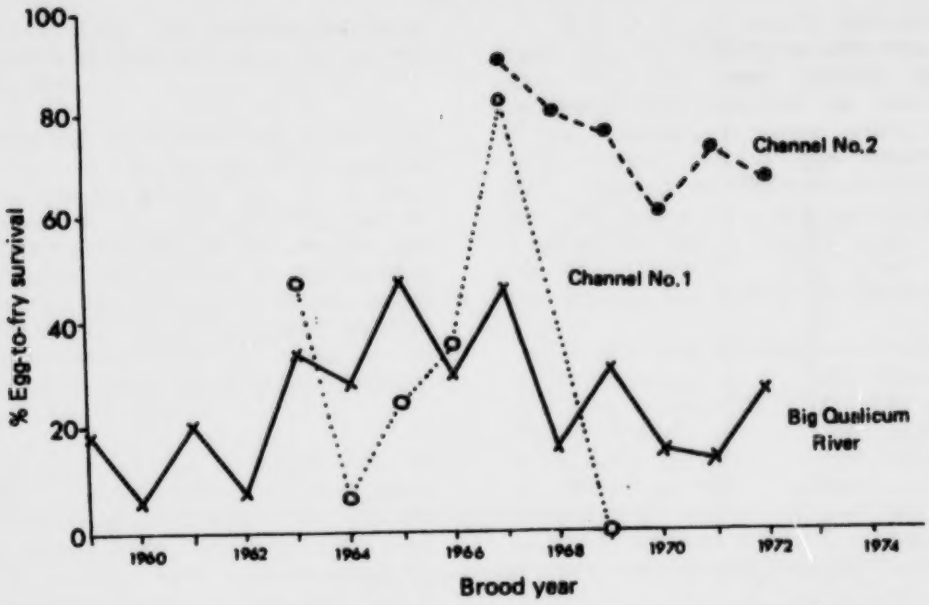


Fig. 39. Chum egg-to-fry survival in Big Qualicum River and in spawning channels No. 1 and No.2, 1959 – 1972 broods.

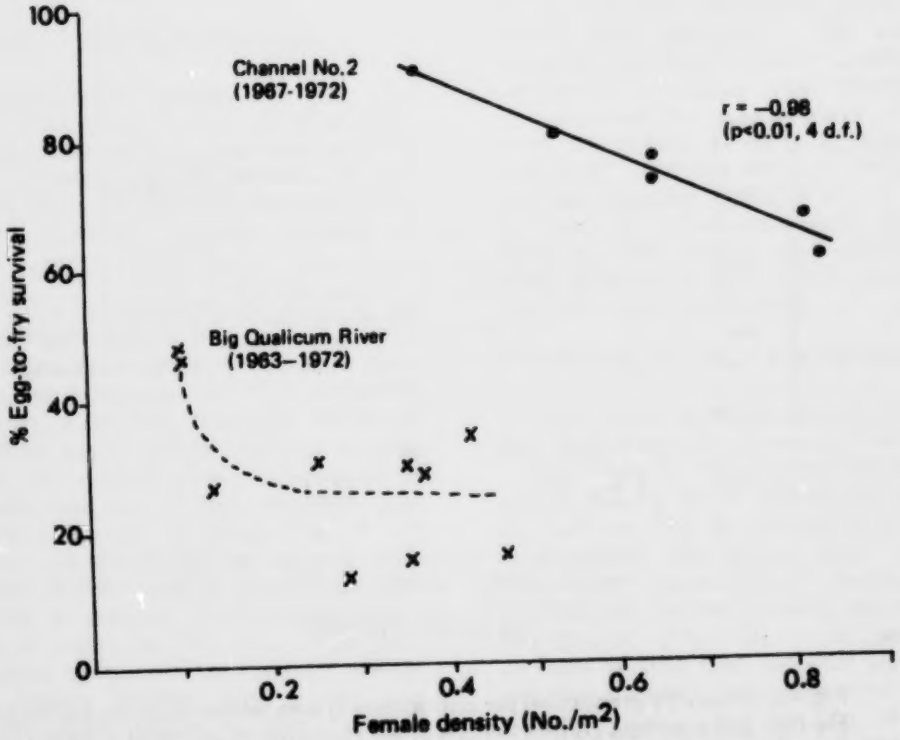


Fig. 40. Chum egg-to-fry survival related to density of chum female spawners in Big Qualicum River and in spawning channel No.2.

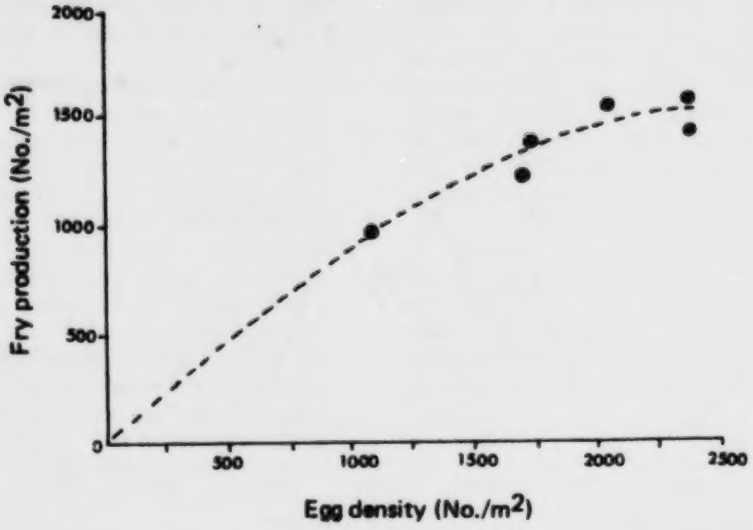


Fig. 41. Chum fry production per unit spawning area related to chum egg density in spawning channel No.2, 1967 – 1972 broods.

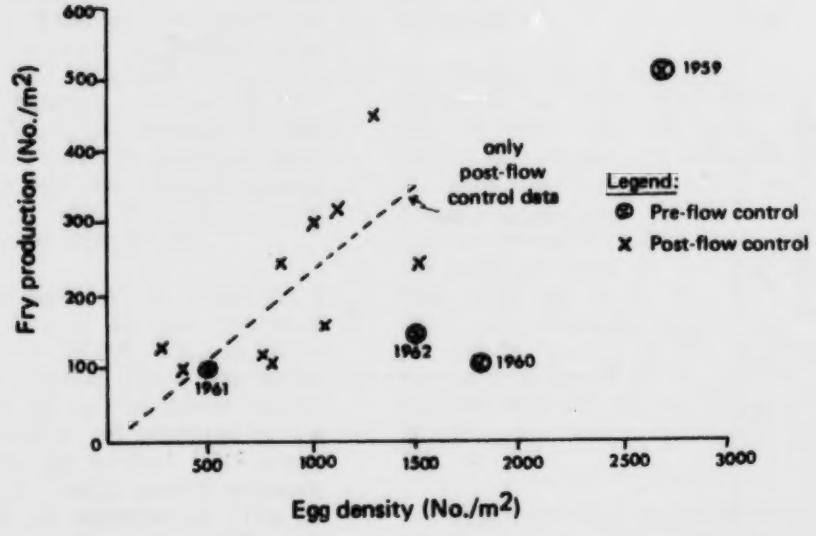


Fig. 42. Chum fry production per unit spawning area related to chum egg density during pre-flow and post-flow control periods in Big Qualicum River, 1959 – 1972 broods.

of about 30 cm. These flow conditions were based on distribution studies of channel No. 1 chum spawners in 1966.

The magnitude of sediment load in the river became apparent in 1968 when 570 m^3 of material were removed from the settling basin at the upper end of channel No. 2. Sediments continued to accumulate in the spawning bed and the gravel was removed, cleaned, and returned to the channel. The tendency for sedimentation to be most severe at the upper end of a spawning channel was also evident in spawning channel No. 1 and in the Abernathy channel, Washington (Thomas and Shelton 1968).

Deterioration of the designed form of channel No. 2 due to spawning fish and gravel cleaning occurred within the first few years of operation. Gravel shifted downstream and filled some of the pools. Bank spawning along the gravel shoulders resulted in increased channel width from 12 m to 15 m. Originally 2.25 m^3/sec flow was sufficient to yield satisfactory water velocities in the channel, but maintenance of these conditions in the wider channel required a flow of about 3 m^3/sec. Despite the above operational problems, freshwater survival in channel No. 2 has remained at high levels.

FACTORS AFFECTING ADULT MIGRATION TIMING

The significant increase in the mean duration of chum and coho adult migration after flow control (comparable chinook data were not available) indicates that the spawners may have been delayed by the reduced peak discharges (high flows often stimulate upstream movement of salmonids).

Major daily influxes of chum adults at the fence often but not always coincided with discharge increases. Timing of migration peaks appeared to be independent of flow increments, provided that a minimum discharge volume of around 5 m^3/sec was surpassed. Such an increase in flow to just above 5 m^3/sec was observed in late November 1968 when a major migration peak also occurred (Fig. 43). At steady flows of less than 5 m^3/sec, adult migration was delayed. This was observed in 1970 when a delayed migration peak occurred on December 7, coincident with a sharp rise in discharge (Fig. 43). That year, adults appeared to hold off the river for several weeks but finally entered under a less than optimal flow regime indicating that residence time in the estuary is also an important factor in migration timing.

Major daily influxes of coho adults at the fence also usually coincided with flow increases (Fig. 43, 1961 data), although these flow increments were sometimes as small as 0.3 m^3/sec. However, in several years, relatively large secondary peaks in coho numbers occurred during steady or decreasing discharge periods (in 1971, the largest daily total was recorded during a period of sharply falling water discharge; Fig. 43). Therefore, factors other than river flow are also important in coho migration timing.

As with chum and coho, major daily influxes of chinook adults at the fence often coincided with flow increases (Fig. 43, 1966 data), but sizable influxes of fish were also recorded during early October even without flow pulses, as in 1960 (Fig. 43). However, flow always increased by end of October and, if flow conditions had been constant, a large number of migrants immediately entered the river.

Temperature did not appear to affect significantly chinook migration timing. For example, chinook migrated prematurely in late summer of 1962 due to construction - related high discharge and despite the mean river temperature of 16°C compared to 11°C to 13°C during the normal migration period in October. As a result of the high water temperature, 21% of the holding females died unspawned. The above incident indicated that flow is much more influential than temperature in chinook river migration timing. It also showed that a large number of chinook may reach the estuary as early as August and that flow control offers a device by which to control upstream migration timing. This is significant in hatchery situations where high holding mortality often occurs among chinook and where delay in migration would result in fish entering the river closer to maturity.

FACTORS AFFECTING SPAWNING DISTRIBUTION

The annual spawning distribution in each of the seven sections of the Big Qualicum River (Table 2) and in Hunt's Creek was determined by species for the period 1969 to 1971 or 1972 (DFO, Big Qualicum file No. 5903-85-(5-f). While the distributions of chum, coho, and chinook overlapped extensively, species specific distribution patterns were maintained from year-to-year (Fig. 25). In general, large portions of both coho and chum populations had discrete spawning areas where other species were scarce (in Hunt's Creek for coho; in most for the river below Hunt's Creek for chum; Fig. 25). Chinook salmon, on the other hand, were not spatially segregated from coho or chum spawners

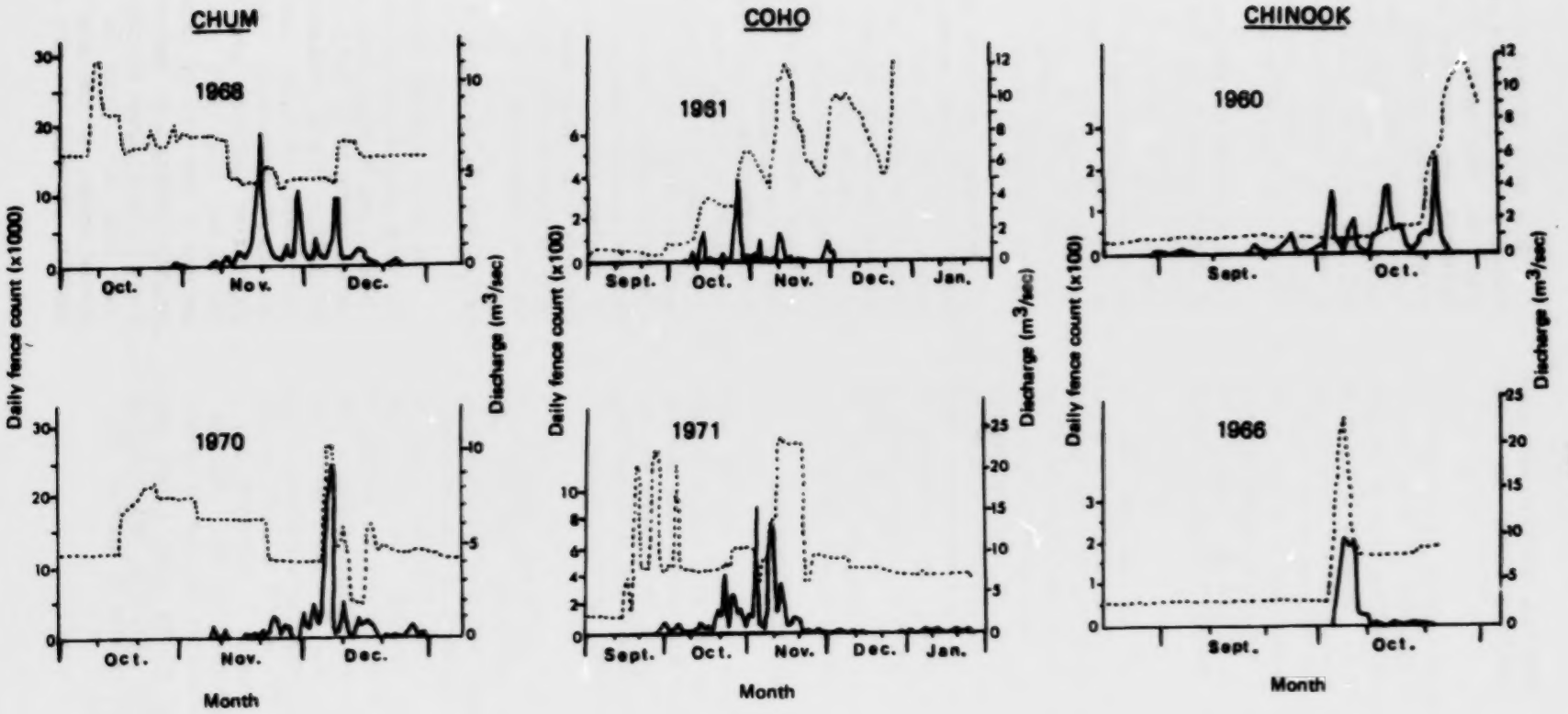


Fig. 43. Adult migration timing of chum, coho and chinook in Big Qualicum River and river discharge for selected years.

(Fig. 25), but were relatively isolated in their spawning timing. Such spatical and/or temporal isolation among species should serve to reduce spawner interference and enhance overall spawning success.

Flow control appeared to have little effect on chum spawning distribution in the Big Qualicum River (Table 55). However, after flow control, coho and chinook spawners were displaced upstream from section 5, and the proportion of coho utilizing Hunt's Creek was reduced (Table 55). The latter may be explained if coho actively avoided the adult trapping facilities at the creek outlet. The upstream displacement of coho and chinook from section 5 is probably more related to stream improvement and the disruption of section 5 at the relocation areas (Fig. 4, Append. 10), than to flow control alone.

The effects of stream improvement on chum spawning distribution are summarized in Table 56. Between 1967 and 1969, the spawning area (particularly section 5) was greatly expanded (Append. 10). Since then, more chum selected the lower river sections (5-7, Fig. 25) as their main spawning area. Mean chum population in section 5 increased from 13,935 before improvement to 47,480 after improvement (Table 56). On the other hand, chum spawning population in sections 1 to 4 either remained constant or dropped, despite substantial increases in total escapement, and the proportion of total chum spawning in these sections fell dramatically (Table 56). Stream improvement, therefore, had an apparently significant effect on chum spawning distribution, particularly by accomodating large chum escapements in the lower river reaches and preventing overflow into the upper reaches which were important for coho and chinook production.

Upstream movement of adult salmon has been often linked to pulses in river discharge, suggesting that spawning distribution may be affected by flow. No evidence supporting this hypothesis was found for chum salmon utilizing lower or upper river sections.

Chum, coho and chinook utilization of the river above Hunt's Creek was examined with reference to chum population above hub 290. No correlation was found. Furthermore, the proportion of chum remaining below the main fence was not a function of total escapement. Escapement totals did not, therefore, directly influence spawning distribution in the Big Qualicum River.

The effect of fence installation on salmonid distribution in the river could not be determined since no comparable data were available prior to 1959.

FRESHWATER SURVIVAL OF BIG QUALICUM RIVER SALMON

The significant increase in mean egg-to-fry survival of Big Qualicum River chum after flow control (13.7% vs 29.1%) indicates that potential gains in freshwater survival through flow control are applicable to entire river systems as well as to small channels such as those at Jones Creek (MacKinnon et al. 1961) and Nile Creek (Wickett 1952). However, no significant increase in freshwater survival after flow control was observed for the Big Qualicum River chinook and coho (see below).

The Big Qualicum River coho had a mean overall egg-to-smolt survival of 1.61%. This was similar to the mean freshwater survival of four coho broods from Waddell Creek, California (1.35%, range 1.16% - 1.56%; Shapovalov and Taft 1954). The above approximate rate for Waddell Creek coho was derived using marked-to-unmarked ratios among returning adults, and adjusting egg deposition for the number of unspawned females but not for partial egg retention believed to be minor. Freshwater survival of 11 coho broods from Minter Creek, Washington, was higher than that at the Big Qualicum River, averaging 3.2% (Salo and Bayliff 1958). In addition, the above survival rate for Minter Creek coho was probably underestimated since the survival estimates were calculated from potential rather than from (possibly lower) actual egg deposition. (Coho production at Minter Creek was comparable to that at Big Qualicum River, ranging from 10,000 to 35,000 smolts per year.)

The Big Qualicum River chinook had a mean overall egg-to-fingerling survival of 3.98%. By comparison, the freshwater survival of the 1966 brood from Cowichan River, B.C., was only 1.31% (Lister et al. 1971). However, this was probably an underestimate since potential rather than (possibly lower) actual egg deposition data were used.

The Big Qualicum river steelhead had a mean egg-to-smolt survival of approximately 0.36%. By comparison, the freshwater survival of the 1933/34 to 1937/38 broods from Waddell Creek was an order-of-magnitude higher, averaging 3.0% (Shapovalov and Taft 1954). However, the Waddell Creek data included fry migrants while the Big

Table 56. Proportions and numbers of chum spawners utilizing different sections of Big Qualicum River during the post-flow control period before (1963-1966) and after (1967-1972) stream improvement.[a]

River section[b]	% Chum spawners[c]		No. chum spawners	
	Before	After	Before	After
1	3.7(2.0)	1.7(1.1)	1,489(1,115)	1,477(1,256)
2	10.0(5.6)	3.2(2.2)	4,007(3,030)	2,887(2,724)
3	8.9(5.9)	3.2(2.7)	3,460(2,298)	3,208(3,355)
4	7.2(3.4)	2.9(1.5)	2,637(1,504)	2,748(2,152)
5	42.6(16.3)	55.0(8.0)	13,935(6,587)	47,480(21,492)
6	4.5(0.3)	5.9(2.5)	1,598(706)	4,534(2,007)
7	23.1(6.3)	28.2(8.6)	7,510(2,411)	21,450(4,512)
Total	100.0	100.0	34,636	83,784

[a] Numbers in parenthesis indicate ± 1 S.D.
[b] See Fig. 25 for location of sections.
[c] Proportions do not correspond exactly to numbers since they are not weighted.

Qualicum River data did not. Since fry contributed 19% to 64% to the downstream totals during the five years of observation at Waddell Creek, it may be calculated that egg-to-smolt survival was in the range of 1.1% to 2.4%. Furthermore, Shapovalov and Taft (1954) backcalculated downstream populations by applying the mark ratio of adult returns to the number of marked juveniles released (rather than by direct enumeration). Any occurrence of differential mark mortality or fin regeneration would result in overestimated juvenile migrant totals and overestimated freshwater survival. This may explain the considerable difference in freshwater survival estimates between Waddell Creek and Big Qualicum River stocks.

FACTORS AFFECTING FRESHWATER PRODUCTION OF CHUM

Factors affecting the freshwater production of chum salmon were examined in three parts:

1. spawning environment, egg retention and fertilization efficiency;
2. incubation environment; and
3. post-emergence predatory losses.

Data for variables examined but not listed in the text tables are shown in Appendix 63.

Spawning environment, egg retention and fertilization efficiency

Egg retention of Big Qualicum River chum varied considerably during the 14-year study period (Fig. 44). In the river, the general tendency was to a lower retention over several years after flow control, followed by an increase since 1969; this increase was also observed in channel No. 2 (Fig. 44). Linear regression analyses were carried out in an attempt to relate the observed retention to spawning conditions. Variables tested alone and in combination included maximum and minimum flows during escapement, the date of 50% completion of adult migration, and the number and density of females. Female density in areas classified as suitable for spawning was the only factor correlated with egg retention (Fig. 45a, $r = 0.68$, 12 d.f., $p < 0.05$). Graphical analysis of the data, however, suggests that this relationship is fortuitous and largely dependent on the high egg retention observed in 1969 (Fig. 45a). On the other hand, grouping all the data for the river and spawning channel No. 2 strongly suggests a positive, non-linear relationship between egg retention and spawner density (Fig. 45b). At less than approximately 0.6 females per m^2, egg retention was less than 8% (except in 1971 and 1972), and averaged approximately 4%. At greater spawner densities, higher retention was generally observed. However, the high retentions of 10.3% and 15.5% observed in the river in 1971 and 1972 respectively, clearly resulted from factors other than numbers of females which were relatively low. Sediment accumulation was the likely cause for this poor performance, although no quantitative data are available to confirm this.

Hunter (1959) found no relation between egg retention and seasonal spawner density for six chum broods in Hooknose Creek, B.C. However, data for four broods of West Kamchatka chum suggest a positive relationship between these two variables (Semko 1954). A similar positive relationship was also found among sockeye in Fulton River and spawning channel No. 1, and in Pinkut Creek spawning channel (Ginetz 1977). It may be that instantaneous spawner density affects spawning success more than the average seasonal density (Lister and Walker 1966), but it is also apparent that other factors such as temperature, flow, migration timing and gravel quality will be influential in some cases.

Spawning success, as measured by egg retention, is not discussed for channel No. 1 because sediment accumulation and gravel cleaning operations resulted in high variation in the quality of spawning gravel. This and other factors for which complete documentation is not available would confound any relationship between fish density and egg retention.

Fertilization efficiency, which includes egg viability and success of sperm to reach or penetrate the eggs, is usually greater than 95%. Hobbs (1937) reported average efficiency values of 99.2% for chinook salmon, brown trout and rainbow trout. Cameron (1940) found 98.2% and 98.6% fertilization efficiencies for pink and sockeye salmon respectively. The few chum redds he examined showed a similarly high fertilization success rate. Coho and chinook salmon and steelhead trout eggs examined by Briggs (1953) were fertilized at an efficiency of 93.4%, 92.4%, and 96.2% respectively. It is likely that the fertilization efficiency is equally high for the Big Qualicum River chum.

Incubation environment

Most egg mortality during incubation occurs

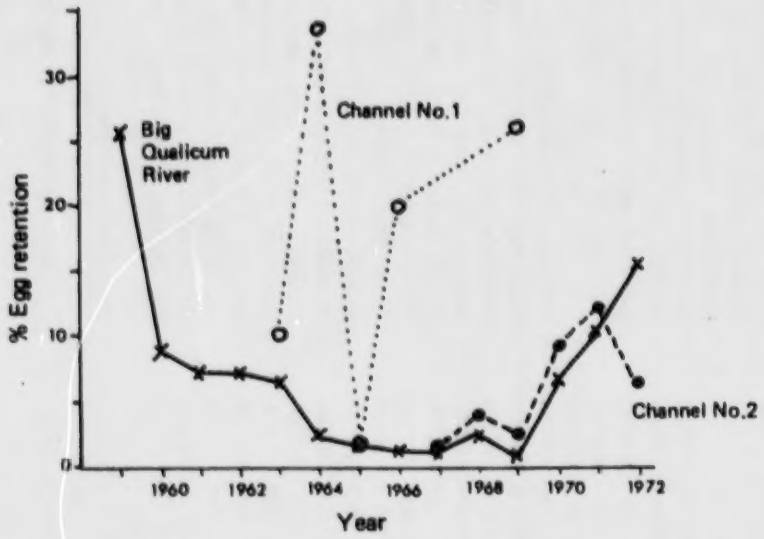


Fig. 44. Chum egg retention in Big Qualicum River and in spawning channels No.1 and No.2, 1959 – 1972.

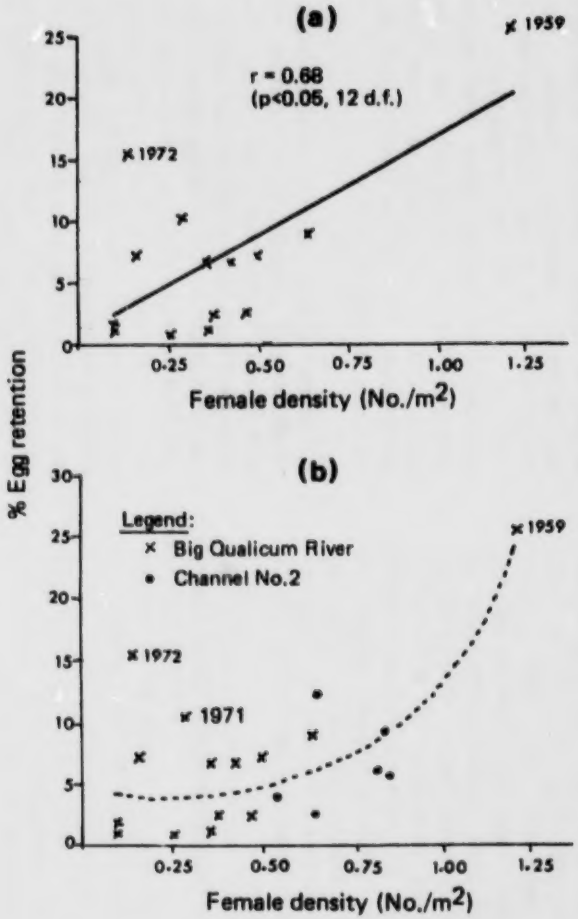


Fig. 45. Chum egg retention related to chum female spawner density in Big Qualicum River above hub 290 (a) and in both the river and spawning channel No.2 (b), 1959 – 1972.

before hatching. Hunter (1959) found that 95% of all pink and chum salmon losses in Hooknose Creek over a two year period occurred during the pre-eyed stage. Semko (1954) and Levanidov (1954) estimated that extruded spawn losses for chum salmon averaged 68% and 25% respectively. A portion of this mortality probably reflects non-viable eggs and incomple fertilization, (see above), while extrinsic factors account for the remaining losses. Bakkala (1970) listed the following environmental factors which may affect egg survival: unsuitable concentrations of ammonia, carbon dioxide and oxygen; extreme low and high flows; presence of light; sedimentation; salinity; parasites, particularly the fungus Saprolegnia; superimposition of redds; and predation on exposed eggs. Some of these factors are examined below.

Extreme fluctuation in streamflow, such as observed in the Big Qualicum River before flow control, has long been recognized as a major adverse factor in freshwater survival of salmonid eggs and alevins (Hobbs 1937; Neave and Wickett 1948, 1949; Neave 1953, 1958; Smoker 1953; Levanidov 1954; Wales and Coots 1955; Wickett 1958; Royce 1959; Hunter 1959; and Gangmark and Bakkala 1960).

Low flows may expose redds to dessication or freezing, especially if high spawner density forced the spawners into peripheral areas. High flows may scour the redds, causing eggs to be washed away; or may wash into the stream silt-bearing material which, when settled out, may cause suffocation of fish eggs.

Chum egg-to-fry survival in Qualicum River more than doubled after flow control although a decline was apparent after 1967 (Fig. 39). High winter discharge was therefore implicated as a major source of pre-flow control mortality among incubating eggs. The observed relation between maximum daily discharge during the incubation period and egg survival is hyperbolic (Fig. 46). At very low flows poor survival might be expected due to bed exposure. This was not experienced at Big Qualicum River. In years of 6 m^3/sec to 25 m^3/sec peak discharges, survival estimates varied widely and factors other than flow probably exerted a predominant influence on egg survival. Survival declined at daily discharge levels of 25 m^3/sec up to over 40 m^3/sec. It is notable that peak daily discharges during the four-year pre-flow control study period were moderate compared to those recorded in earlier years. In 1958, for example, daily discharge reached 380m^3/sec compared to maximums of less than 100 m^3/sec during 1959 to 1963.

At the Big Qualicum River, effects of water temperature on salmonids during egg incubation suggested a possible adaptive mechanism. Chum eggs incubating in the river showed a strong positive correlation ($r = 0.93$, $p < 0.001$) between total required A.T.U.'s and mean water temperatures (Fig. 47), suggesting that chum respond to colder conditions by more efficient use of the available thermal energy for development, with the result that variation in migration date was kept to a minimum. Coho and chinook from Big Qualicum River showed a similar trend to lower A.T.U. requirements in response to lower temperatures.

At controlled flows and temperatures, sedimentation and superimposition of redds were two factors most likely to affect egg survival in the Big Qualicum River. Increased levels of sediment in the gravel result in low permeability, toxic levels of waste products, and oxygen deficiency. Sedimentation in the Big Qualicum River was probably significant, as indicated by sedimentation studies in spawning channel No. 1 (Giles MS 1967). Briefly, the study showed that sedimentation increased in all channel sections from January to March of 1966, with largest initial increase observed in the uppermost sections. Conversely, oxygen levels in the intergravel samples declined to less than 3 ppm by March of that year with lowest concentrations observed in the uppermost channel sections. Of the 255 samples analyzed for oxygen during the study only five had saturation levels of 90% or more. The above findings are summarized in Figure 38. Accumulation of sediment in the absence of winter freshets was at least partially responsible for reduced egg survival in the river during later years of the study and necessitated maintenance work.

Superimposition of redds, closely related to spawner density, is a significant factor in egg survival. In channel No. 2, egg survival showed a strong negative correlation with female spawner density ($r = -0.98$, $p < 0.01$; Fig. 40). Also in Big Qualicum River, highest freshwater survivals occurred at spawner densitites of only 0.01 females per m^2 of spawning area (1965 and 1967 data), but no consistent effect on egg survival was evident at densities ranging from 0.14 to 0.47 females per m^2 (Fig. 40). The less well defined relationship in the river is attributed to the variability in the quality of river areas

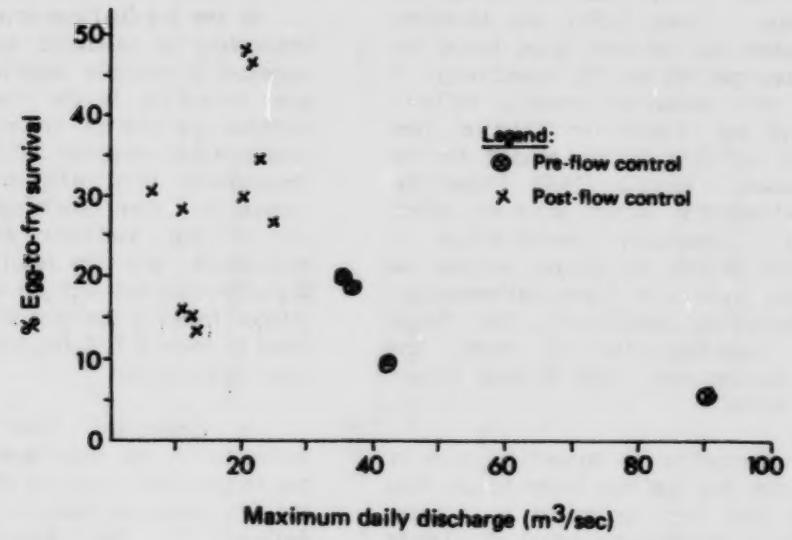


Fig. 46. Chum egg-to-fry survival related to maximum daily discharge during incubation (after completion of escapement) before and after flow control in Big Qualicum River, 1959 – 1972 broods.

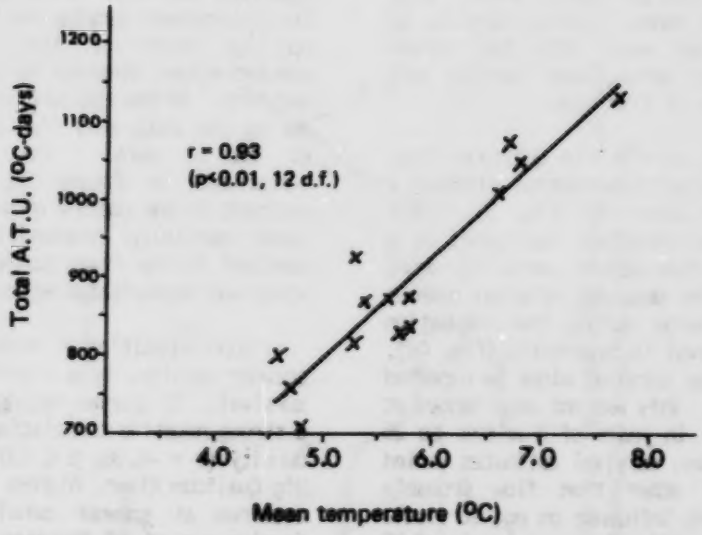


Fig. 47. Total required accummulated thermal units for chum incubation related to mean water temperature during incubation in Big Qualicum River, 1959 – 1972 broods.

classified as suitable for spawning and to the wide time period over which spawning occurred in the river compared to the channel.

Negative relationship between egg survival and spawner density was also reported for pink and chum salmon in Hooknose Creek (Hunter 1959), pink salmon in the Seton Creek spawning channels (IPSFC 1971), and sockeye salmon in the Babine River system (Ginetz 1977).

Estimates of chum egg-to-fry survival for the 1964 to 1972 broods based on potential egg deposition for Big Qualicum River were compared to Fraser River survival data (DFO, unpublished data) to assess whether freshwater survival was influenced by gross climatic conditions or other factors which might simultaneously affect stocks over a wide geographical area. A tendency to positive correlation was found ($r = 0.62$, 7 d.f.) but this was not statistically significant.

Predation on exposed eggs was not quantified for the Big Qualicum River. However, the presence during chum spawning of loose eggs in the water and in the stomachs of trout and sculpins indicated that some eggs were lost during this phase. Reed (1967) observed Dolly Varden feeding on eggs carried downstream from a redd over which a pair of chum were spawning, while a prickly sculpin was actively feeding within the redd.

Other variables which might affect egg survival were examined but did not explain the observed variation. Included were the minimum temperature during the early incubation period, the temperature increment during the last three months of incubation period, mean temperature during incubation, duration of incubation, and accumulated thermal units.

Post-emergence predatory losses

Predatory losses during fry migration can be significant, although passive migration at night should minimize them. Hunter (1959) found that approximately 500,000 chum and pink fry (about 45% of the mean fry production) were taken by predators each year at Hooknose Creek, except during an exceptionally small run when up to 85% of the run could be lost. Pink fry migration patterns are quite similar to those of chum and predation data for either of the two species are probably relevant for the other. Cameron (1941) examined the sources of freshwater mortality for the 1940 brood pink salmon in McClinton Creek, B.C., and estimated up to 60% predation on the emergent fry. McNeil (1965), however, found virtually no predatory losses among pink fry migrating from Sashin Creek, Alaska. Tagnaz'yan (1970) investigated the relation between size of emergent pink populations and predation and concluded that predation was more important in small streams than in large ones. The Big Qualicum River is rated as a medium sized river by Tagnaz'yan's (1970) classification.

Coho smolts, prickly sculpins and aleutian sculpins were present in large numbers during chum fry migrations in Big Qualicum River. Large sculpins exposed to high densities of fry in live boxes in Big Qualicum River preyed on the young fish. Hunter (1959) found that sculpins angled from Hooknose Creek contained pink and chum fry in their stomachs. Patten (1971) found that of the four sculpin species present in two tributaries of the Columbia River, the prickly sculpin was the most important and largest chinook fry predator. Patten (1971) also found that 0.9% to 83.3% of sampled sculpins contained salmon fry in their stomachs and estimated that this predator consumed 1.3% to 3.9% of the hatchery-reared chinook fry during three releases. Coho smolts are also known to consume fry that are highly concentrated (Pritchard 1936; Hunter 1959). Steelhead smolts and cutthroat trout represent a further source of predation but they were not sufficiently abundant in Big Qualicum River to have a significant impact on the salmonid fry.

In general, the effect of predators on the Big Qualicum River chum fry, although not quantified, is probably minor. Any predation occurring upstream from the Big Qualicum River counting fence was reflected in the calculated egg-to-fry survival. The studied populations believed to be heavily consumed (for example, pink and chum fry in Hooknose Creek; Hunter 1959) were much smaller (0.5 million - 2 million) than those in the Big Qualicum River system where high fry numbers alone (for example 63 million in 1970; Append. 23), were likely to saturate predator capacity. However, during meager years (1960 to 1962 broods), predation may have had a significant effect. It is unlikely that the predators could adapt to increased fry production through higher population densities since the fry are available only seasonally. However, enhancement of species such as coho and steelhead which remain in the system for one or more years could have a two-pronged effect on chum populations. The fingerlings may consume chum

fry. They could also, if present in sufficient abundance, serve to maintain larger numbers of other piscivorous species, such as sculpins and trout, during the remainder of the year. These larger fish may be expected to switch to chum fry when available. Exceptionally large populations of coho and steelhead were present during the latter years of the Big Qualicum River study.

FACTORS AFFECTING FRESHWATER PRODUCTION OF COHO, CHINOOK AND STEELHEAD

The capacity of a stream to support rearing juvenile coho, chinook and steelhead trout within a suitable environment is limited by factors such as food and space. Smolt production of the above species in Big Qualicum River varied considerably during the period of study (Fig. 48) suggesting that the carrying capacity of the river was not constant from year to year. Some physical and biological parameters which may have affected this production are examined below.

Limiting factors during incubation

Production of coho, chinook and steelhead fry is affected by many of the same factors pertaining to chum salmon egg-to-fry survival. These factors include spawning environment, incubation conditions and predation. Assuming that larger eggs give rise to larger and hardier progeny, genetic or nutritional (egg size) factors may be also involved. This was suggested by a positive correlation ($r = 0.79$, $p < 0.01$) between coho smolt weight and female spawner length (Fig. 49). However, no evidence exists that the above factors (expect possibly the genetic factor) affect the production of smolts, given that fry populations are sufficient to saturate the available rearing area. At the Big Qualicum River, "excess" emergent-size fry of coho, chinook and steelhead generally migrated each spring (only in 1963 no net migration of coho fry from the river was observed). In addition, while the freshwater survival of chum increased significantly after flow control reflecting better incubation conditions, coho and chinook smolt production showed no significant effect. It seems most probable, therefore that constraints on the production of river populations of coho, chinook and steelhead are operating during the rearing rather than incubation periods.

Physical factors and stream rearing capacity

Low summer flows were previously implicated as an important determinant of a system carrying capacity for freshwater rearing salmonids (Neave and Wickett 1948, 1949; Smoker 1953; Harvey and Davis 1970). Low flows may also prevent emergence of fry or result in their being trapped in isolated backwaters. Greatest effect of low flows would be felt by juveniles with the longest freshwater residence period (steelhead) and least by juveniles with the shortest freshwater residence period (chum) (Neave 1958). Maximum winter flow may be critical if no suitable rocky substrate exists for the overwintering juveniles. Such habitat requirements were observed for both chinook and steelhead (Hartman 1965; Everest 1969). Temperatures may limit carrying capacity by controlling food supply or by exceeding the tolerance range for salmonids. Since the flow control project at the Big Qualicum River resulted in lower winter freshet discharge and in higher flows and lower temperatures during summer (Figs. 20 and 21), the carrying capacity of the river may have changed.

The number and biomass of migrant chinook and coho smolts (steelhead were excluded due to the difficulty of assigning migrants to brood year) were compared to mean, maximum and minimum flows, and to mean and maximum temperatures experienced during the rearing period. No relationship was observed between chinook production and temperature or flow data during March to May in the year of emergence (Append. 64). Coho production in the river was also not significantly correlated to mean flow, maximum flow or mean temperature during the 13 months starting from May in the year of emergence (Append. 65). However, the consistently larger mean annual size of river coho smolts compared to Hunt's Creek smolts (Table 36) was probably related to the warmer water temperatures in the river compared to the creek (Fig 11). Coho biomass in the river was linearly correlated to minimum summer flow ($r = 0.68$, $p < 0.05$; Fig. 50) and to maximum water temperature ($r = -0.65$, $p < 0.05$; Fig. 51), although the latter relationship is best described as curvilinear (Append. 65). A multiple linear correlation between coho biomass and these two variables was also statistically significant ($r = 0.71$, $p < 0.05$, 8 d.f.).

The observed reduction in coho yield at higher maximum temperatures (Fig. 51) may indicate that resource availability, such as food, does not increase proportionately to demand, at least in the Big Qualicum River. It may be hypothesized that individual fingerlings require more food and space at higher

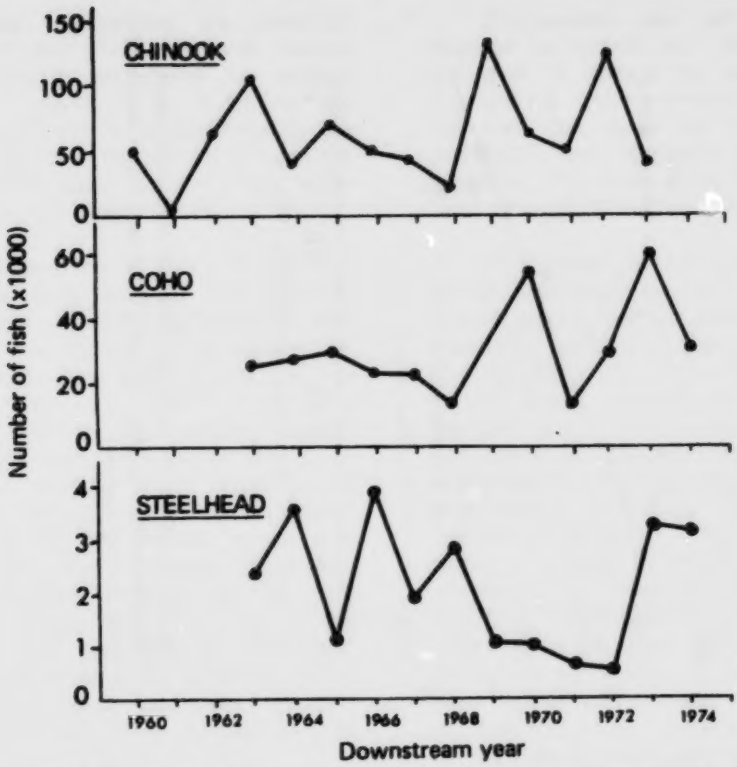


Fig. 48. Number of chinook, coho and steelhead smolts migrating from Big Qualicum River above hub 290, 1960 – 1974.

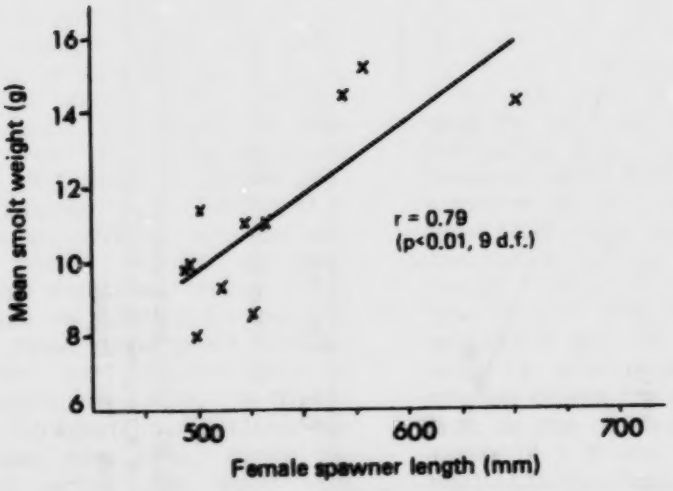


Fig. 49. Coho smolt weight related to female spawner length in Big Qualicum River, available 1959 – 1972 broods.

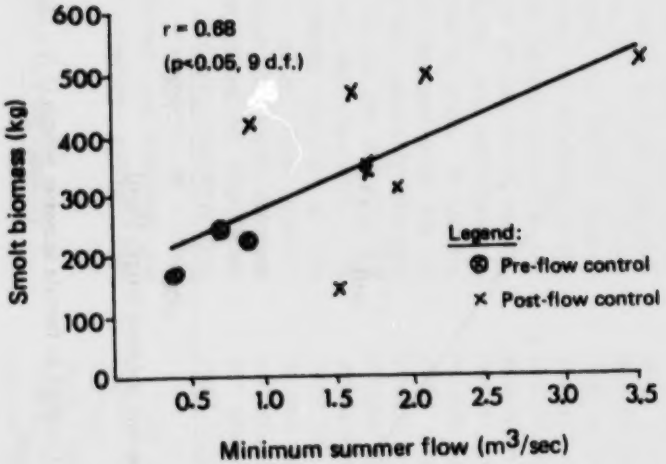


Fig. 50. Coho smolt biomass related to minimum summer flow during rearing in Big Qualicum River, available 1959 – 1972 broods.

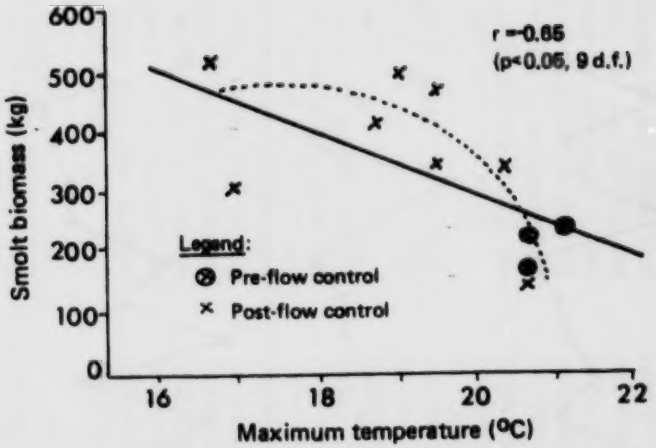


Fig. 51. Coho smolt biomass related to maximum water temperature during rearing in Big Qualicum River, available 1959 – 1972 broods.

temperatures, thus constraining the potential population numbers and yield, although numbers were not as closely correlated to maximum temperature ($r = -0.46$, $p > 0.05$) as was biomass. This hypothesis is substantiated by the observation of a positive correlation between the level of aggression among coho fry and water temperatures (Mason and Chapman 1965).

Another consideration is that the physical data employed for these analyses were measured near the river mouth at the camp bridge. Both temperature and flow regimes in the upper river sections were less favourable during the pre-flow control period than the river mouth data suggest. For example, mean monthly summer temperatures at the Horne lake outlet were up to 6.7°C higher than near the river mouth in the pre-flow control period, while in subsequent years, differences between the two sites were slight (Append. 8). Thus, although the maximum daily mean temperature recorded at the camp bridge was 21.4°C (August 1963), the upper river temperatures in 1959 to 1963 may well have exceeded the tolerable range for juveniles (0°C - 24°C; Brett 1952). These conditions may have contributed to the lower smolt biomass produced prior to flow control (Figs. 50 and 51).

Intraspecific Effects

While the rearing environment undoubtedly influences resource requirements for individual fish, social behaviour also plays a role. Young coho fry, observed in experimental stream channels, established territories within 10 days of emergence and displayed nipping and chasing behaviour the first few days, followed by threat behaviour (Mason and Chapman 1965). Dominant coho fry were usually the largest or most brightly coloured (Hoar 1951). The subordinate coho fry (Chapman 1962; Mason and Chapman 1965) and chinook fry (Edmundson et al. 1968) held in artificial stream environments, were excluded from preferred feeding stations and were eventually displaced downstream. Fraser (1969) found that both coho and steelhead fry when held at high densities showed reduced growth rates and biomass production, and attributed this to increased intraspecific competition. In the Big Qualicum River, intraspecific competition may have occurred among coho since, during the post-flow control period, coho smolts were smallest in the 1970 and 1973 downstream migrations (1968 and 1971 brood years respectively) which had by far the greatest smolt abundance (Table 33).

Displacement may not be an immediate response to aggression. Reimers (1973) noted that even if chinook fry were attacked all day they did not leave a particular area until night and that the delay was most likely due to phototactic and rheotactic responses. However, migrating fry numbers are proportional to the level of aggression (Mason and Chapman 1965).

Displacement of fry is most dramatic in the period immediately following emergence when large migrant populations are usually evident. If this downstream pulse is at least partially the result of competition for resources then migrant fry totals should increase at higher numbers of emergent fry. The numbers of emergent Big Qualicum River chinook, coho and steelhead were not determined but egg deposition could provide an index (although egg-to-fry survival undoubtedly varies). The relationship between number of chinook fry migrants and actual chinook egg deposition revealed a slight positive trend but this interpretation was tenuous (Fig. 52). Coho fry, on the other hand, appeared to saturate the system and migrate in large numbers when coho egg deposition exceeded approximately three million (Fig. 53). Assuming egg-to-fry survival of 25% (the 14 brood year average for chum salmon; Table 57), the rearing capacity in the Big Qualicum River would be filled at coho fry population levels of 750,000.

Kalleberg (1958) found that as Atlantic salmon fingerlings grew, their territorial space demands expanded. If this is the case, displacement of fingerlings should continue throughout the active growth period unless mortalities (pathological, predatory, etc.) are sufficiently great to make available additional space for the remaining individuals, or unless the habitat area preferred by the juveniles increases during this period. The latter suggestion is not unrealistic since Lister and Genoe (1970) found that both coho and chinook juveniles in the Big Qualicum River progressed through a series of preferred habitats as they grew larger: from back eddies, log jams or undercuts to open bank areas, and finally to fast water. In addition, mortality is great for both coho and chinook fry during the rearing period. Based on chum egg-to-fry survival data, only an average of 7.3% coho fry and 15.8% chinook fry remained in the river to smolt stage (Table 57).

The above suggests that intraspecific competition for resources in the Big Qualicum River probably controlled to some extent the

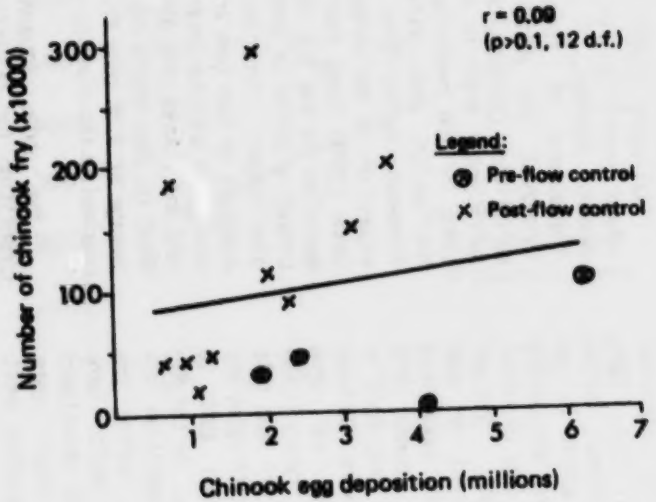


Fig. 52. Number of chinook fry migrants related to actual chinook egg deposition in Big Qualicum River, 1959 – 1972 broods.

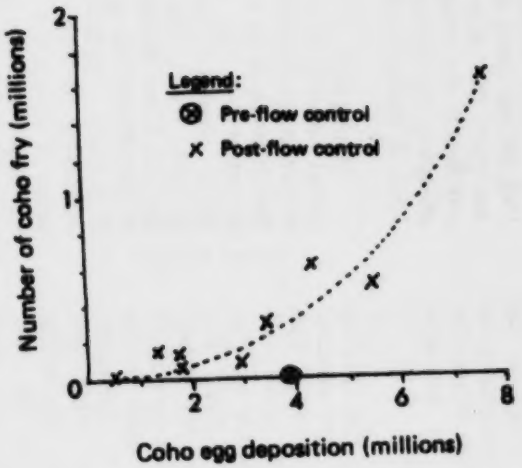


Fig. 53. Number of coho fry migrants related to actual coho egg deposition in Big Qualicum River, available 1962 – 1972 broods.

Table 57. Estimates of fry-to-migrant stage survivals of Big Qualicum River coho and chinook above hub 290, based on chum egg-to-fry survival data, 1959-1972 broods.

Brood year	Chum egg-to-fry survival (%)	Coho				Chinook			
		Egg deposition (millions)	Estimated No. emergent fry[a]	No. migrant smolts	Estimated fry--to smolt survival(%)	Egg deposition (millions)	Estimated No. emergent fry[a]	No. migrant fingerlings	Estimated fry-to-fingerling survival(%)
1959	19.0	1.595	303,000	_b	_b	6.267	1,190,000	49,400	4.2
1960	5.7	0.691	39,600	-	-	4.128	237,000	4,600	1.9
1961	20.2	1.140	230,000	24,500	10.6	1.932	390,000	63,300	16.2
1962	9.8	3.853	378,000	26,800	7.1	2.415	237,000	105,000	44.4
1963	34.6	-	-	29,100	-	1.928	667,000	38,100	5.7
1964	28.5	5.501	1,568,000	23,200	1.5	1.291	368,000	69,900	19.0
1965	48.1	4.350	2,090,000	22,600	1.1	3.642	1,750,000	48,000	2.7
1966	30.0	3.436	1,031,000	12,800	1.2	3.167	950,000	40,500	4.3
1967	46.6	1.362	635,000	34,900	5.5	1.114	519,000	19,600	3.8
1968	16.4	1.757	288,000	53,200	18.5	0.777	127,000	131,000	103.1
1969	30.7	1.796	551,000	13,300	2.4	2.296	705,000	61,000	8.7
1970	15.6	2.953	455,000	28,800	6.3	0.940	145,000	45,300	31.3
1971	13.7	7.672	1,036,000	59,700	5.8	2.051	277,000	120,000	43.3
1972	25.8	0.547	147,000	30,100	20.5	0.675	181,000	35,300	19.4
Mean ± 1 S.D.	24.7	2.519	673,350	29,900	7.3±6.7	2.330	553,000	59,400	15.8±15.2[c]

[a] Based on chum egg-to-fry survival data.
[b] Main river and Hunt's Creek counts combined.
[c] Excluding 1968 brood.

production of coho juveniles and to a lesser extent that of chinook juveniles. Steelhead production was not analysed due to insufficient data.

Interspecific Effects

Chinook salmon juveniles, numerically the dominant stream-rearing anadromous species in the Big Qualicum River system (Table 57) are present in the river only in spring. Interactions with young coho may occur at this time but are minimized by temporal and spatial segregation. Although chinook and coho spawning sites overlapped in the upper 4 km of the river, chinook spawned earlier; chinook fry emerged earlier at a larger size and grew faster than coho, thereby moving through the typical succession of preferred habitats ahead of coho fry (Lister and Genoe 1970). Chinook fry downstream totals were completely random relative to coho egg deposition which suggests that interspecific competition is negligible at this stage. Positive correlation ($r = 0.63$, $p < 0.05$) between the numbers of chinook fingerlings and coho smolts produced by brood year (Fig. 54) also suggests that interspecific competition was not important during rearing, but rather that common factors control the freshwater production of both species.

Steelhead and coho fingerlings might compete for resources, especially when present at high densities. Laarman (1969) found that in a laboratory raceway steelhead outcompeted coho for a limited food supply. Fraser (1969) combined these species at different densities in experimental stream channels. Both inter- and intraspecific competition occurred at high densities but interspecific competition was absent at lower densities. Several studies indicate that coho and steelhead occupy different microhabitats in nature, suggesting that competition is minimal. Hartman (1965) reported that during months of active feeding, trout occupied riffles while coho occupied pools. Underwater observations in Big Qualicum River revealed that sympatric coho and steelhead were vertically stratified, with steelhead near the bottom and coho higher in the water column.

The above observations suggest that interspecific competition for resources was not a significant controlling factor in the production of coho, chinook or steelhead juveniles in the Big Qualicum River.

EFFECTS OF STREAM IMPROVEMENT

Stream-rearing species were of major concern during the stream improvement program due to possible deleterious effects of improvement activities. These concerns included:

1. The effect of improvement work on river stability. However, flow control minimized the impact of this factor and observations at work sites showed that risk was minimal.

2. The effect of siltation which occurred downstream from working areas. This was a temporary by-product of river development, and short duration flushes reduced the silt load to levels considered insignificant.

3. The effect of grading which denuded the work area of its benthic invertebrate fauna, the primary food source for rearing fish. Since complete recolonization fueled by drifting organisms probably occurred within weeks (Waters 1964), and since the affected area was small at any one time, this disruption was probably of only minor importance.

4. The effect of operating machinery stationed in the river. However, the absence of abnormal migration patterns during improvement activities negates this concern.

5. The effect of rearing area availability. The project eliminated some natural rearing sites but the introduction of weirs and artificial pools compensated, at least partially, for lost rearing capacity.

Gains made in the freshwater survival of Big Qualicum River chum due to flow control, spawning channel construction, and improvement of the river spawning environment resulted in large adult returns from 1968 onward (Table 6). Many of these fish were accommodated in channel No. 2, but the river spawning load also increased (Fig. 55). The egg-to-fry survival for the 1968 and 1970 to 1972 river broods was lower than in earlier years and may be explained by the negative correlation ($r = -0.69$, $p < 0.05$) between egg-to-fry survival and spawner density since flow control commenced (Fig. 56). If the

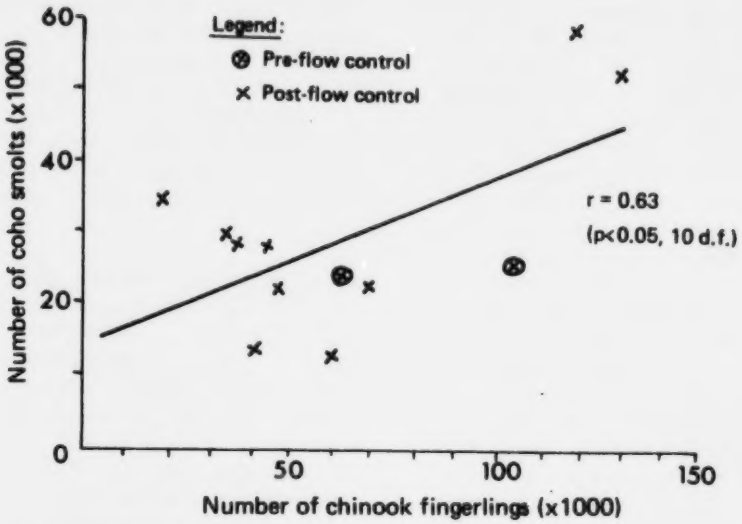


Fig. 54. Coho smolt production related to chinook fingerling production for coincident broods in Big Qualicum River, 1961 – 1972 broods.

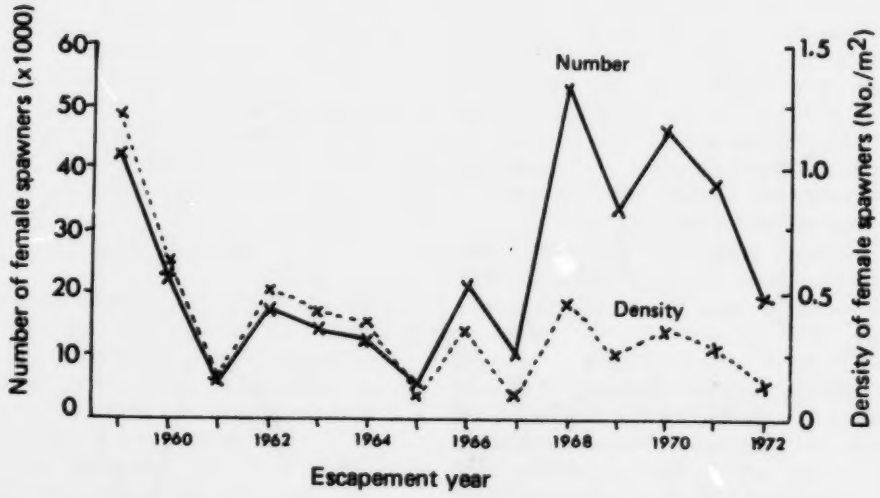


Fig. 55. Annual abundance and density of chum female spawners in Big Qualicum River, 1959 – 1972.

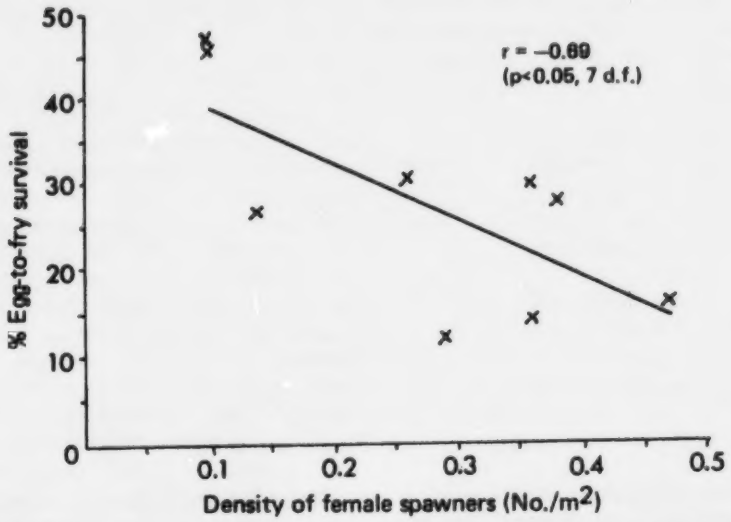


Fig. 56. Egg-to-fry survival of chum related to density of chum female spawners in Big Qualicum River after flow control, 1964 – 1972 broods.

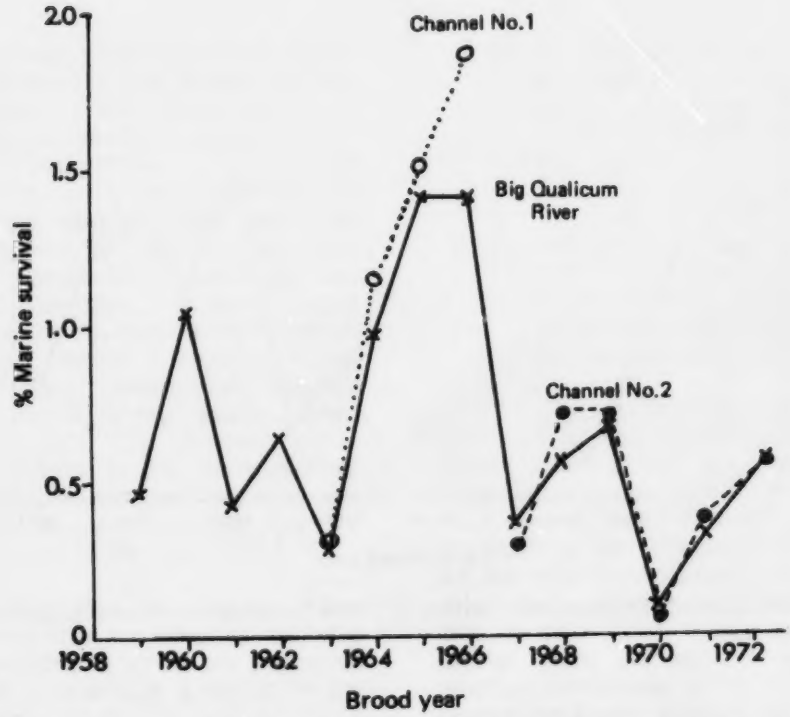


Fig. 57. Marine survival of chum salmon from Big Qualicum River and spawning channels No.1 and No.2, 1959 – 1972 broods.

river spawning area had not been expanded, thereby maintaining moderately low spawner densities (Fig. 55), freshwater survival may have been much lower. For example, in the peak spawning year of 1968, when approximately 53,000 chum females utilized the river above hub 290, density under 1964 river conditions would have reached 1.6 females per m^2 which greatly exceeds the level of density (1 female/m^2) recommended by McNeil (1965).

In general, mean chinook and coho migrant production and egg-to-migrant survival were not significantly different during the pre-improvement (1959-1963 broods), minor improvement (1964-1965 broods) and major expansion and maintenance (1966-1972 broods) periods (Table 58). Annual production of these two species was highest for the 1968 and 1971 broods (Fig. 48), both of which experienced either expansion or maintenance activities during the freshwater rearing period.

The above results indicate that physical improvement techniques were successfully applied to the Big Qualicum River with substantial expansion of chum spawning area without loss of rearing capacity, and without apparent detriment to the rearing coho and chinook juveniles.

FACTORS AFFECTING MARINE SURVIVAL OF BIG QUALICUM RIVER SALMONIDS

The marine survival of Big Qualicum River chum was independent of whether the fish were produced in the spawning channels or the mainstem, since survival rates varied very little among sources (Fig. 57). In the following examination of factors possibly related to marine survival, data for chum fry produced in the river were considered as representative of the system.

Characteristics of migrating juveniles

Migrating coho, chinook and steelhead fry were generally assumed to perish. Some coho scales from Big Qualicum River returns, particularly among jacks, were interpreted as having migrated as fry but it was considered more likely that these scales had regenerated. Both Drucker (1972) and Shapovalov and Taft (1954) failed to find any indication of coho fry surviving to adulthood in their analyses of adult scales. Experimental evidence supports the non-viability of coho fry at sea. Coho, chinook and sockeye fry, when placed in 31.8‰ seawater, suffered high mortality within a few days (Weisbart 1968). Furthermore, the physiological adaptations required to survive in the ocean develop only gradually in rearing coho. Otto and McInerney (1970) showed that coho juveniles selected higher salinities as they grew older. Kennedy et al. (1976) found that even if coho fry survived, they might not grow in saltwater; and their seapen studies revealed that while some coho smolts grew well, others with visible parr marks did not, and instead succumbed to disease within six months. It thus seems unlikely that migrating coho fry make any significant contribution to adult production.

Chinook entering the ocean as fry were assumed to perish for the same reason as advanced for coho fry. Reimers (1973) observed that chinook fry which migrated out of the Sixes River within a few weeks of emergence were not represented by any of the sampled adults indicating negligible fry survival.

Marine survival of Big Qualicum River chum fry was not correlated with fry length, weight or condition coefficient. Although size at release appears to be related to ocean survival (Mathews and Senn 1975), the variation in juvenile size at Big Qualicum River was apparently too slight to influence survival at sea.

Marine survival to escapement of coho smolts and of chinook fingerlings from Big Qualicum River also was not correlated with migrant length, weight, condition coefficient or migration timing. By comparison, marine survival of Puget Sound hatchery coho was related to both smolt size and downstream timing (Mathews and Buckley 1976). It is notable that marine survival of the 1970 brood chinook fingerlings was among the lowest recorded (Table 46) as was also the case for chum of that brood year (Table 27). This low survival coincides with the latest 50% completion date for juvenile migration observed over 14 chinook broods (Table 45), and also with the coldest mean temperatures recorded in January through March at Pine Island during the first winter in the ocean (Append. 64). Results of hatchery release experiments at the Big Qualicum River tend to confirm the correlation between late juvenile migration and poor marine survival. Two groups of chinook juveniles released in June survived to escapement at rates approximately nine times greater than those of seven chinook groups released in July or August of that year (Fraser et al. unpublished MS). Presumably, the late migrants encountered particularly unfavourable oceanic conditions,

Table 58. Effects of stream improvement on mean production (± 1 S.D.) and freshwater survival (± 1 S.D.) of coho and chinook smolts in Big Qualicum River, 1959-1972 broods.

Brood years	Year of summer residence	Stream improvement activities	Coho		Chinook	
			Smolt production	Egg-to-smolt survival(%)	Fingerling production	Egg-to-fingerling survival(%)
1959-1963	1960-1964	Pre-improvement	26,800±2,300	1.42±1.03	52,100±36,700	2.10±1.74
1964-1965	1965-1967	Minor mechanical activities	22,900±400	0.47±0.07	59,000±15,500	3.37±2.89
1966-1972	1967-1973	Major expansion and maintenance activities	33,300±18,000	1.99±1.84	64,700±43,500	5.50±5.33

Table 59. Steelhead freshwater rearing period in B.C. streams as determined by scale analysis of sports-caught adults (n gives sample size).

Stage	Location	Year	n	% Rearing				Reference
				1 Year	2 Years	3 Years	4 Years	
Adult	Big Qualicum River	1964/65-1966/67	546	1.8	85.6	12.6	0	Peterson and Lyons (1968)
Adult	S.W. British Columbia	1949-58	1,650	1.8	39.9	54.9	3.4	Withler(1966)
Adult	Vancouver Island	1969/70	101	1.0	66.3	31.7	1.0	Narver and Withler(1971)

such as low food and temperature levels, during their early ocean rearing stages.

Scales of steelhead adults sports-caught in the Big Qualicum River indicated that most originated from age 2+ and 3+ smolts (Table 59), although, as stated previously, majority of juveniles migrated from the Big Qualicum River at age 1+ and 2+. Withler (1966) and Narver and Withler (1971) also observed that age 2+ and 3+ steelhead smolts were the dominant group in subsequent adult returns (Table 59). Shapovalov and Taft (1954) made similar observations among steelhead from Waddell Creek, California. The above indicates that older steelhead smolts have a higher smolt-to-adult survival than yearling smolts. Recent hatchery studies have also shown that, for any particular species, larger smolts usually have a higher marine survival than smaller smolts, provided the fish are released during the normal migration season.

Wild juveniles of a given species may also enjoy enhanced marine survival proportional to their rearing time prior to downstream migration. This is definitely the case for steelhead (see above) and probably for chinook and coho.

The marine survival of chum fry also appears to be directly related to length of the rearing period. Compared to the Big Qualicum River, the Fraser River chum fry are usually more successful in the ocean (Fig. 58). This may reflect the greater distance travelled in freshwater by Fraser River juveniles and large size of the Fraser River estuary compared to that at Big Qualicum River. Both these factors tend to impose a longer rearing period on Fraser River chum before they enter saltwater and these juveniles tend to be larger than Big Qualicum River chum at this crucial stage (Levy and Northcote 1981).

A direct relationship between species marine survival and size of migrant juveniles, as well as duration of freshwater rearing period, is evident among the Big Qualicum River salmonids where mean marine survivals ranged from a low of 0.66% for chum to a high of 25% for steelhead (Table 60).

Number of migrants

Chum marine survival varied from poor to good when the system downstream migrants totalled less than 25 million, but high survivals were never recorded for larger broods (Fig. 59). This relationship is only of limited use, however. For example, the downstream total for the 1969 brood was 63.1 million fry, the largest during the study, yet the marine survival was relatively high (0.69%) and similar to the 0.66% overall mean survival recorded for the 1959 to 1972 broods. Futhermore, adult returns as a function of fry totals are described equally well, or better, by a linear relationship ($r = 0.65$, Fig. 60) than by a saturation-type curve. A saturation curve would be expected if the relation of marine survival to fry totals was hyperbolic. The available data do no permit clarification of whether or not chum fry production in Big Qualicum River system did in fact exceed the estuarine or marine carrying capacity in some years.

A significant positive linear correlation was observed between coho adult returns and numbers of migrating coho smolts ($r = 0.88$, $p < 0.05$; Fig. 61). The reduced size of coho smolts in the years of highest production numbers (see section on factors affecting coho freshwater survival) apparently had little effect on subsequent marine survival.

Among the Big Qualicum River chinook, reduced marine survival was observed at wild juvenile totals exceeding 40,000 to 50,000 fish (Fig. 62). In particular, brood years with high marine survival rates (7.36% for the 1960 brood and 6.26% for the 1966 brood), had downstream juvenile totals of only 4,970 and 43,700 respectively, while lower survival rates of less than 2% were often characterized by wild juvenile totals exceeding 50,000 fish (Fig. 62). Returns of wild chinook adults to Big Qualicum River related to wild fingerling downstream totals, appeared to peak at approximately 1,500 adults (Fig. 63). This corresponds to total maximum adult production of 6,000 to 10,000 chinook depending on the catch-to-escapement ratio.

Studies suggest that estuarine rearing capacity may be exceeded at high juvenile population densities. For example, chinook juveniles from the Sixes River, Oregon, had negligible estuarial growth during three summer months in a year of large downstream production (Reimers 1973). Considering the very small area of the Big Qualicum River estuary (approximately 140,000 m^2; P. Mace, pers. comm.), it is possible that similar limiting processes may be occurring in years of high chinook fingerling production in that river. However, other data do not support

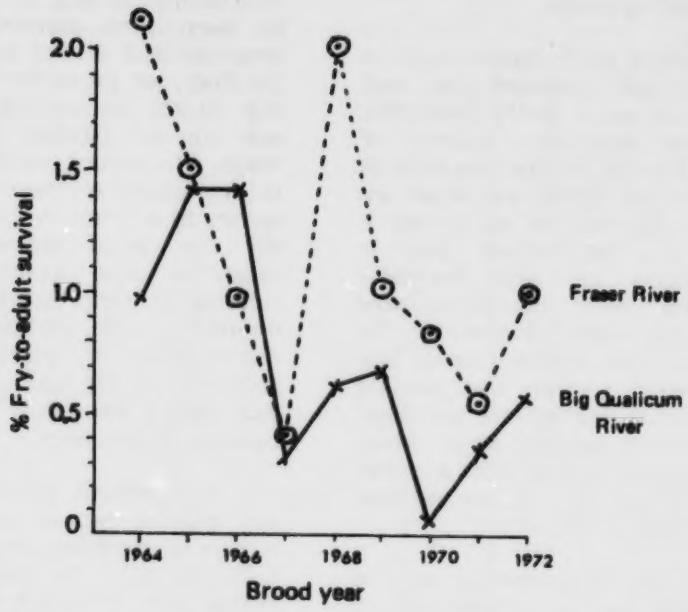


Fig. 58. Marine survival of chum salmon from Fraser River and Big Qualicum River systems, 1964 – 1972 broods.

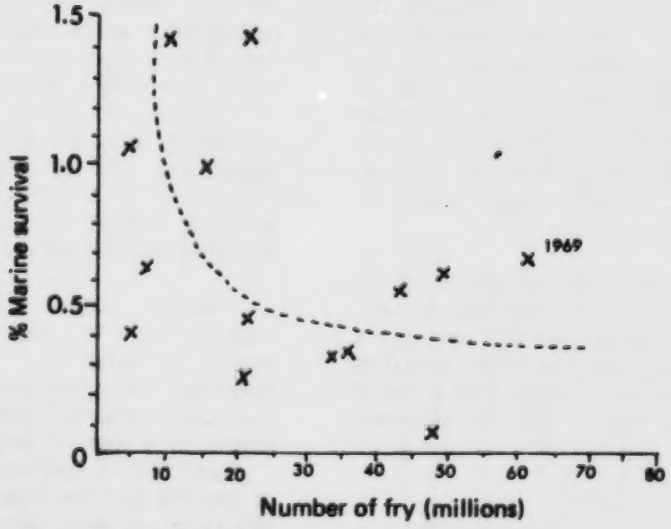


Fig. 59. Marine survival of chum salmon related to chum fry downstream totals for Big Qualicum River system, 1969 – 1972 broods.

Table 60. Migrant weight and freshwater and marine survival estimates for Big Qualicum River chum, chinook, coho and steelhead for available 1959-1972 broods (ranges given in parenthesis).

Species	Mean migrant weight (g)	Freshwater survival (%)	Marine survival (%)	Egg-to-adult survival (%)
Chum	0.36	24.7(5.7-48.1)	0.66(0.08-1.41)	0.17(0.01-0.68)
Chinook	3.94	3.98(0.11-16.9)	1.88(0.20-7.36)	0.04(0.01-0.08)
Coho	11.2	1.61(0.37-5.47)	10.9(5.4-15.5)	0.17(0.03-0.43)
Steelhead	52.2	0.36	25	0.09

[a] Excluding marine catch of chinook, coho and steelhead.

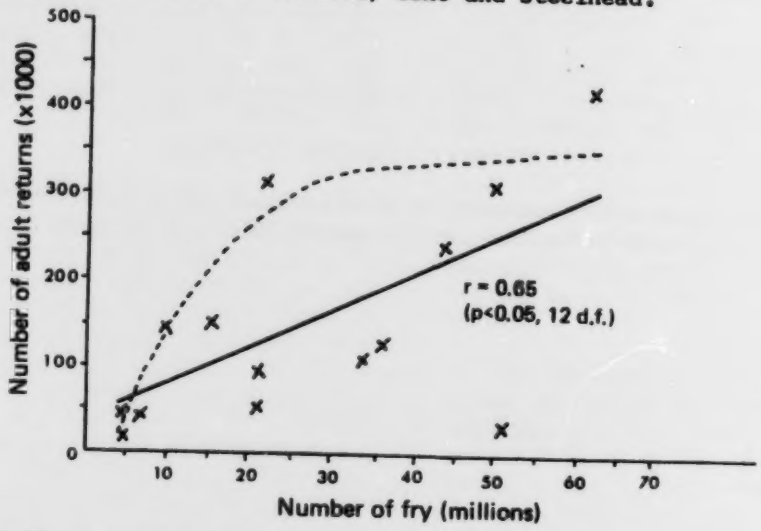


Fig. 60. Chum adult returns related to chum fry downstream totals for Big Qualicum River system, 1959 – 1972 broods.

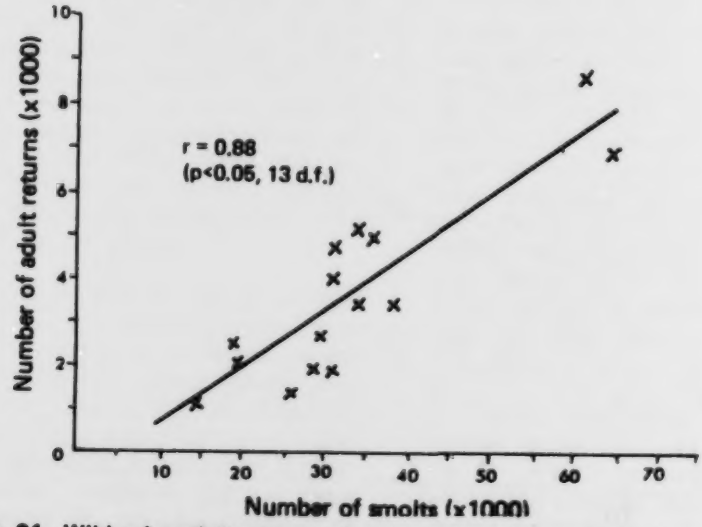


Fig. 61. Wild coho adult returns related to wild coho smolt downstream totals, 1958 – 1968 broods (Big Qualicum River and Hunt's Creek data) and 1969 – 1972 broods (Big Qualicum River data).

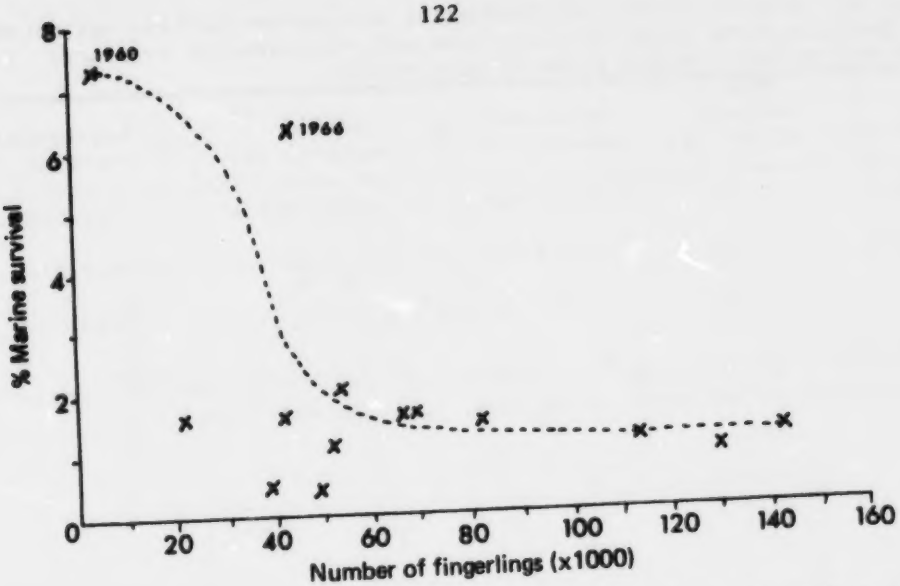


Fig. 62. Marine survival to escapement of wild chinook related to chinook fingerling downstream totals for Big Qualicum River system, 1959 – 1972 broods.

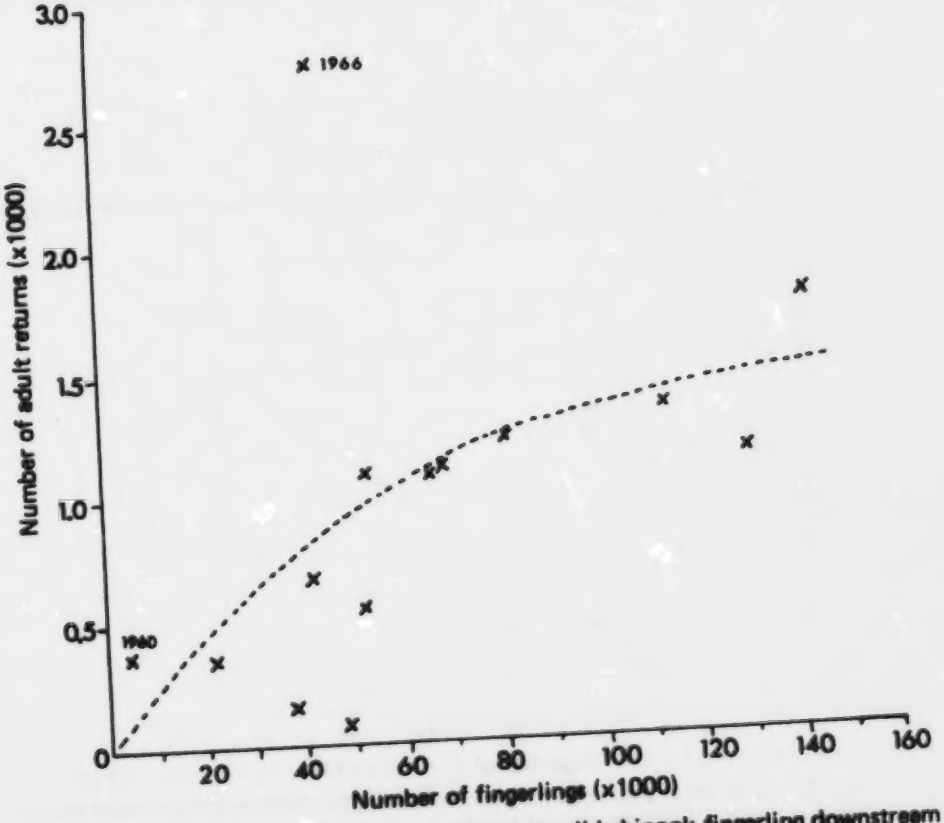


Fig. 63. Wild chinook adult returns related to wild chinook fingerling downstream totals for Big Qualicum River system, 1959 – 1972 broods.

this hypothesis. For example, chinook juveniles were observed to migrate through the Big Qualicum River estuary in less than a day (P. Mace, per. comm.) indicating little use of the estuary for rearing. Also, in later years (eg. 1979) chinook escapement to the system exceeded 8,000 adults which is well above the expected peak yield (Fig. 63).

The effect of hatchery chinook releases on the marine survival of wild chinook is difficult to assess, although the total migrant population of 448,500 juveniles from 1968 brood and 555,100 juveniles from 1972 brood (Append. 61) may have resulted in competition for resources. However, hatchery releases, particularly in the early years of production, occurred much later than natural migrations thereby reducing potential competition.

Marine environment

The poorest marine survival (0.07%) was recorded for the 1970 brood chum fry from Big Qualicum River system. Poor ocean survival was also recorded for Big Qualicum River chinook of that brood year and unusual check marks were noted in scales of other species. Preliminary analysis of Fraser River chum stocks also revealed relatively low survival for the 1970 brood but not to the extreme experienced by Big Qualicum River stocks (Fig. 58). The above trends imply that fish from the 1970 brood year generally experienced unfavourable marine environment.

Ocean temperatures and/or salinities during early marine life were implicated by Wickett (1958) and Blackbourn (1977) as factors related to pink salmon fry-to-adult survival. The early marine period was selected since it is generally assumed that most mortalities occur during the first few months (Parker 1966). Since pink and chum salmon share many life history characteristics, similar factors may play a role in the success of the two species.

Marine survival of Big Qualicum River chum showed no significant correlation with mean salinities measured from April to August in the year of fry migration near Chrome Island, just northwest of the Big Qualicum River (Fig. 33, Append. 63). However, a significant ($p < 0.05$) positive linear correlation was observed between chum marine survival and mean surface ocean temperatures measured at the above site from April to August in the year of fry migration ($r = 0.64$; Fig. 64, Append. 63). The strong tendency to high survival in the upper end of the experienced temperatures is expected since both marine productivity and chum growth rates are directly related to ocean water temperatures.

A curvilinear relationship was observed between surface ocean temperatures measured from January to March (Append. 63) at Pine Island in Queen Charlotte Strait (Fig. 34) and marine survival of chum in their first winter at sea (Fig. 65). The marine distribution of chum during their first winter is not known exactly but, based on present knowledge, Pine Island is representative of their general geographical location. This area may also represent the general marine temperature regime because the annual fluctuations in temperature at different sites are similar. The observed relationship does not necessarily imply that most mortalities occur during this period, but does indicate that temperatures from January to March at Pine Island may be somehow related to some important determinants of survival which exert an impact before, during or perhaps even after this time period.

No linear relationship was found between summer temperatures at Chrome Island and winter temperatures at Pine Island. The coldest summer was not followed by the coldest winter, nor was warmest summer followed by warmest winter. It is not surprising then, that the survival trends relating to these factors differed (Figs. 64 and 65).

A notable feature of the above relationship between winter temperatures at Pine Island and chum marine survival is the apparent occurrence of an optimum temperature of approximately 7.0°C to 7.5°C (Fig. 65). At other locations within practical geographical boundaries this optimum might shift either way by one degree. It may be that meaningful biological interactions are reflected by this optimum. However, the value of winter temperatures as an indicator of future chum salmon returns is questionable since very slight changes in temperature measurements could have a large impact on the estimated fry survival.

Unlike chum, the Big Qualicum River coho and chinook showed no useful relationship between marine survival to escapement and mean surface water temperatures measured at Chrome Island during April through August of the downstream year or at Pine Island during January through

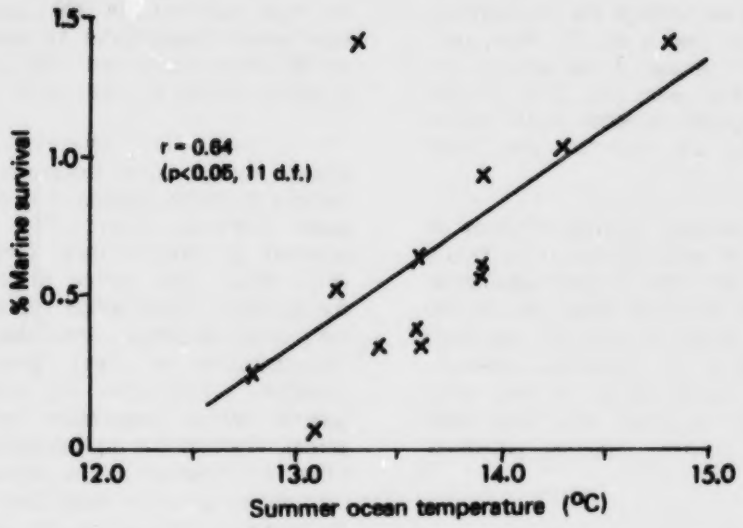


Fig. 64. Marine survival of chum salmon from Big Qualicum River system related to mean ocean surface temperature at Chrome Island, measured from April through August in the year of fry outmigration, 1960 – 1972 broods.

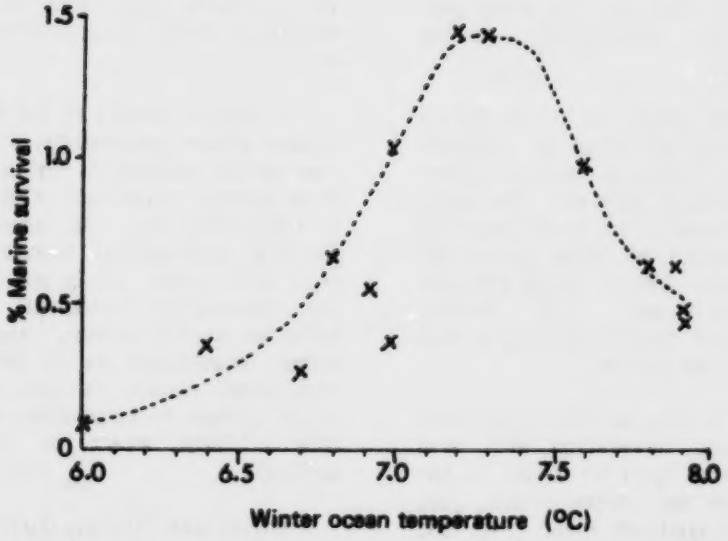


Fig. 65. Marine survival of chum salmon from Big Qualicum River system related to mean ocean surface temperature at Pine Island, measured from January through March in the first year of juveniles at sea, 1959 – 1972 broods.

March of the first winter at sea (Appends. 64 and 65). Water salinities at Chrome Island (Append. 64 and 65) were also unrelated to coho and chinook marine survival.

The above attempts to relate marine survival of coho and chinook (based on escapement totals) to environmental factors must be treated with caution since the escapement totals exclude losses from fishery exploitation (these differ among geographically displaced stocks and may vary from year to year), and present only a lower limit of smolt survival. For example, Argue (1976) estimated that 23,300 Big Qualicum River coho from 1971 brood were caught in the sport and commercial fisheries. This preliminary estimate indicates that coho catch from the 1971 brood was at least equal to the escapement for that brood year (16,500 fish; Table 38). Since coho smolt survival to escapement for the 1971 brood was 10.9%, overall marine survival was at least 20%.

Preliminary exploitation estimates for Big Qualicum River chinook (based on recoveries of nose tagged 1971 brood fish) were approximately 15% to 30% higher than those for coho. Changes in fishing effort and success would therefore result in a relatively greater change in chinook survival estimates based on escapements compared to coho. On the other hand, catches of chinook of a single brood are spread over four years compared to only one year for coho; this would tend to attenuate short term fishery effects. Examination of total B.C. chinook landings (B.C. Catch Statistics, Dept. Env., Fish. Mar. Serv., Pacific Region) revealed no patterns of commercial fishing pressure and success which would account for the high survival-to-escapement rates recorded for the 1960 brood (7.36%) and 1966 brood (6.26%) (Table 46).

BIOLOGICAL IMPLICATIONS OF FRESHWATER REARING

As was discussed previously, compared to chum, the extended freshwater rearing period of coho, chinook and steelhead resulted in larger size of migrant juveniles which was in turn directly related to marine survival of the latter species. However, the extended freshwater rearing period also resulted in reduced freshwater survival as implied by Big Qualicum River data where steelhead had the lowest mean freshwater survival (0.36%) and chum the highest (24.7%) (Table 60). Evaluation of these data indicates, however, that the opposite effects of duration of rearing period on freshwater and marine survivals neutralize each other. The net result, indicated by egg-to-adult survival, shows a relatively narrow survival range from 0.04% for chinook to 0.17% for chum and coho (Table 60). Adjusting these rates for exploitation losses (best available estimates of catch to escapement for chinook and coho are 4:1 and 1.4:1.0 respectively), gives chinook and coho survival rates of 0.20% and 0.41% respectively and the overall species egg-to-adult survival range becomes 0.09% for steelhead to 0.41% for coho (steelhead survival estimates are conservative since some interception in commercial salmon fisheries is expected). Based on these adjusted survivals, mean fecundity data, and an assumed 50% sex composition, approximate returns per adult spawner are 2.6 chum, 5.4 chinook, 5.3 coho and 1.7 steelhead. Adult production is therefore relatively consistent among species despite the magnitude of variability in their survival during the component marine and freshwater stages.

SUMMARY

1. The Big Qualicum River Development Project was designed in the early 1960's primarily to increase freshwater survival of chum salmon. The project included flow and temperature control, construction of two spawning channels, and stream improvement. This report contains data collected for 14 brood years (1959-1972) of anadromous fish in the system, with the 1959 to 1962 broods serving as predevelopment controls.

2. Big Qualicum River watershed, located in the east part of Vancouver Island, has an area of 150 km^2 and includes upper Qualicum River, Horne Lake, the mainstem Big Qualicum River and Hunt's Creek. The system supports all five species of Pacific salmon: chum are numerically dominant; coho and chinook are next in importance; while pink and sockeye are scarce; steelhead trout also inhabit the system.

3. Big Qualicum River flow was controlled by damming Horne Lake outlet, tunnelling lake water to riverbed at base of second falls, and diverting Hunt's Creek flow. Flow control eliminated high and low flow extremes, and resulted in higher mean summer and lower mean winter flows. Temperature control, operational from May/June through October, resulted in lower summer temperatures at river mouth by up to 4°C.

4. Spawning channel No. 1 operated from 1963 to

1969 and provided 2,800 m^2 of spawning gravel for approximately 2,000 chum. Spawning channel No. 2 operated from 1967 onward and provided 12,000 m^2 of spawning gravel for approximately 20,000 chum.

5. Stream improvement was initiated in 1964 and included increase in spawning area, improvement of spawning and egg incubation environment, and increase in cover and holding pools for adults and juveniles.

6. Chum in Big Qualicum River

Annual chum escapement to the river during 1959 to 1972 averaged 61,000 fish (range 14,000 - 125,000).

Median adult migration date averaged November 28 and was similar before and after flow control. Duration of the run averaged 82 days and increased significantly after flow control (from 68 to 87 days). Spawners died approximately 13 days after leaving the sea. Spawner density was highest in the lower river sections.

Chum generally returned at age 3 (30.5% of total returns), 4 (67.1%) and 5 (2.4%).

Length of 3, 4 and 5 year old chum averaged 555 mm, 592 mm and 607 mm respectively.

Females comprised on the average 51.3% of chum spawners.

Fecundity averaged 3,069 eggs per female.

Egg retention averaged 7.0% and declined significantly after flow control (from 12.3% to 4.9%) implying improved spawning conditions.

Actual egg deposition above hub 290 averaged 70.0 million per year (range 17.1 million - 172.9 million); below hub 290 it averaged 21.8 million per year (range 5.2 million - 43.9 million).

Chum eggs incubated from December to May for approximately 156 days, with no significant pre-flow and post-flow control difference. After flow control, mean incubation temperatures and required A.T.U.'s declined.

Fry production above hub 290 averaged 14.4 million per year (range 3.4 million - 32.0 million) and was considerably higher after flow control than before (17.3 million vs 7.9 million). Fry production below hub 290 averaged 4.8 million per year.

Median fry migration date averaged May 11 and was delayed significantly after flow control (from May 3 to May 13). Duration of downstream run averaged 110 days and increased significantly after flow control (from 95 to 117 days).

Fry length, weight and condition coefficient averaged 38.9 mm, 358 mg and 0.62 respectively, and were similar before and after flow control.

Egg-to-fry survival averaged 24.7% (range 5.7% - 48.1%); survival more than doubled after flow control (from 13.7% to 29.1%).

7. Chum in spawning channel No. 1

During 1963 to 1969, up to 2,540 chum spawned annually in channel No. 1.

Median adult migration dates were similar for channel No. 1 and river adults. Duration of the run averaged 27 days and was much shorter than that in the river for the same time period (86 days).

Adult age, length and sex composition were similar to those for river chum.

Egg retention averaged 18.1% and was significantly higher than that for river chum (2.6%).

Actual egg deposition averaged 2.11 million per year (range 0.65 million - 3.75 million), or about 3% of river system egg deposition.

Egg incubation period and the required A.T.U.'s were similar to those for river chum.

Fry production averaged 0.71 million per year (range ~0 - 1.78 million).

Median fry migration date averaged May 10 and was similar to that for river fry. Duration of downstream run averaged 58 days and was significantly shorter than that for river fry (111 days).

Fry length, weight and condition factor were similar to those for river fry.

Egg-to-fry survival averaged 32.9% and was similar to that for river chum; however, the range was highly inconsistent (~0% - 82.5%) indicating inadequate spawning and incubation environments.

Adult returns from channel No. 1 (1963 - 1967 broods) totalled about 40,000 chum and accounted for 5% of the system returns during that period.

8. Chum in spawning channel No. 2

During 1967 to 1972, 8,266 to 20,286 chum spawners utilized channel No. 2 per year.

Median adult migration dates were similar for channel No. 2 and river adults. Duration of the run averaged 18 days and was much shorter than that in the river for the same time period (88 days).

Adult age, length and sex composition were similar to those for river chum.

Egg retention averaged 5.9% and was similar to that for river chum (6.2%).

Actual egg deposition averaged 25.6 million per year (range 13.0 million - 33.6 million), or about 16% of river system egg deposition.

Egg incubation period and the required A.T.U.'s were similar to those for river chum.

Fry production averaged 18.4 million per year (range 11.7 million - 22.5 million).

Median fry migration date averaged May 19 and was similar to that for river fry. Duration of downstream run averaged 74 days and was significantly shorter than that for river fry (121 days).

Fry length, weight, condition coefficient and swimming endurance were similar to those for river fry.

Egg-to-fry survival averaged 74.5% (range 60.6% - 90.1%) and was three times higher than that for river chum (24.9%).

Adult returns from channel No. 2 (1967 - 1972 broods) totalled about 478,000 chum and accounted for 38% of the system returns during that period.

9. Annual chum escapement to the total system ranged from a low of 17,900 fish for the 1961 brood to a high of 183,000 fish for the 1969 brood. Estimated chum catches for the total system ranged from a low of 300 fish for the 1962 brood to a high of 250,000 fish for 1969 brood. Exploitation rates during 1962 to 1975 ranged from less than 1% to 67%.

10. Marine survival of Big Qualicum River chum (1959-1972 broods) averaged 0.66% and was similar for pre-flow and post-flow control periods. Marine survival of channel No. 1 and channel No. 2 chum fry averaged 1.21% and 0.45% respectively, and was similar to the river values for comparable time periods.

11. Coho in Big Qualicum River

Annual coho escapement to the river during 1959 to 1972 averaged 3,000 fish (range 1,200 - 7,400).

Median adult migration date averaged October 28 and was similar before and after flow control. Duration of the run averaged 106 days and, as for chum, increased significantly after flow control (from 87 to 113 days). Spawners died approximately 33 days after leaving the sea. Spawner density was highest just upstream of Hunt's Creek confluence.

Coho generally returned at age 2 (20.6% of total returns) and 3 (79.4%).

Length of jacks and 3 year old coho averaged 342 mm and 527 mm respectively.

Females comprised on the average 55.7% of coho spawners.

Fecundity averaged 2,574 eggs per female.

Egg retention averaged 22.0% indicating poor spawning conditions, and was not significantly different before and after flow control.

Actual egg deposition above hub 290 averaged 2.82 million per year (range 0.55 million - 7.67 million). Spawning was not considered to occur below hub 290.

Coho eggs incubated from December to May for approximately 167 days, with no significant pre-flow and post-flow control difference. After flow control, mean incubation temperatures and required A.T.U.'s declined, as was observed for chum.

Fry production above hub 290 averaged 347,000 per year (range 0 - 1,620,000); smolt production averaged 29,900 per year (range 12,800 - 59,700); no response of juvenile production to flow control was evident. Smolt production below hub 290 averaged 2,150 per year (range 1,000 - 4,650).

Median fry and smolt migration dates averaged May 13 and May 26 respectively and did not change significantly after flow control. Duration of smolt downstream run averaged 119 days and, as for chum, increased significantly after flow control (from 92 to 132 days).

Smolt length, weight and condition coefficient averaged 98.5 mm, 11.2 g and 1.11 respectively; smolts were significantly larger after flow control.

Smolts migrated at age 1+ (98.4% of total) and 2+ (1.6%).

Egg-to-smolt survival averaged 1.61% (range of 0.37% - 5.47%) and did not differ significantly before and after flow control.

12. Coho in Hunt's Creek

Annual coho escapement to Hunt's Creek during 1959 to 1971 averaged 544 fish (range 103 - 933).

Adult age, length and sex composition were similar to those for river coho.

Egg retention averaged 3.5% and was significantly lower than that for concurrent river coho broods (15.5%), indicating a better spawning environment in the creek.

Actual egg deposition averaged 0.64 million per year (range 0.13 million - 1.29 million).

Fry production averaged 40,700 per year (range ~0 - 81,200); smolt production averaged 5,100 per year (range 600 - 8,100).

Median fry and smolt migration dates averaged May 8 and May 15 respectively, and were a week earlier than those for river juveniles.

Smolt length, weight and condition coefficient averaged 86.2 mm, 7.3 g and 1.10 respectively; creek smolts were significantly smaller than river smolts, probably due to lower creek temperatures.

Smolts migrated at age 1+ (97.0% of total) and 2+ (3.0%).

Egg-to-smolt survival averaged 1.59% (range 0.19% - 6.35%) and did not differ significantly from that of river coho.

Marine survival to escapement of Big Qualicum River system coho averaged 10.8% (range 5.4% - 15.5%).

13. Chinook in Big Qualicum River

Annual chinook escapement to the river during 1959 to 1972 averaged 1,300 fish (range 600 - 2,400).

Median adult migration date averaged October 4 and was similar before and after flow control. Duration of the run averaged 70 days. Spawners died approximately 18 days after leaving the sea. Spawner density was highest in uppermost river section.

Chinook generally returned at age 2 (21.2% of total returns), 3 (28.1%), 4 (48.6%) and 5 (2.1%).

Length of 2, 3, 4 and 5 year old chinook averaged 479 mm, 697 mm, 802 mm, and 831 mm respectively.

Females comprised on the average 45.3% of chinook spawners.

Fecundity averaged 5,373 eggs per female.

Egg retention averaged 11.0% and was not significantly different before and after flow control.

Actual egg deposition above hub 290 averaged 2.33 million per year (range 0.67 million - 5.27 million). Spawning was not considered to occur below hub 290.

Chinook eggs incubated from October to May for approximately 174 days, with no significant pre-flow and post-flow control difference. After flow control, mean incubation temperatures and required A.T.U.'s declined, as was observed for chum and coho.

Fry migrants above hub 290 averaged 99,000 per year (range 3,000 - 297,000). Fingerling migrants above hub 290 averaged 59,400 per year (range 4,600 - 131,000); below hub 290, fingerlings averaged 4,700 per year (range 400 - 10,400). No response of juvenile numbers to flow control was evident.

Median fry and fingerling migration dates averaged April 10 and June 12 respectively; fingerling median date was significantly delayed after flow control (June 2 vs June 17). Duration of fry and fingerling downstream runs averaged 71 days and 56 days respectively.

Fry length, weight and condition coefficient averaged 43.5 mm, 618 mg and 0.76 respectively; fingerling length, weight and condition coefficient averaged 72.7 mm, 3.94 g and 1.04 respectively. Juvenile sizes were similar before and after flow control.

Egg-to-fingerling survival averaged 3.98% (range 0.11% - 16.85%) and did not differ significantly before and after flow control.

Marine survival to escapement of Big Qualicum River chinook averaged 2.04% (range 0.42% - 7.36%).

14. Steelhead trout in Big Qualicum River system

Annual steelhead escapement during 1964/65 to 1972/73 averaged 618 (range 366 - 788).

Median adult migration date averaged January 26. Duration of the run averaged 155 days.

Most steelhead returned at age 4_3 (58.3% of total returns) and 5_3 (24.9%).

Length increased from 653 mm for age 4_3 fish to 813 mm for age 6_3 fish.

Fecundity averaged 3,866 eggs per female.

Potential egg deposition averaged 0.73 million per year (range 0.42 million - 1.06 million).

Smolt migrants averaged 2,665 per year (range 641 - 4,688).

Median smolt migration date averaged May 22 and was significantly later after flow control (May 13 vs May 25).

Smolts were larger after flow control (179 mm, 60.5 g) than before (144 mm, 35.5 g).

Egg-to-smolt survival averaged 0.36%.

Marine survival (including sports catch) was approximately 25%.

Biological evaluation

15. Spawning channel No. 1 failed as a chum production facility due to poor spawning and incubation environment. Problems included low channel gradient, inadequate water velocity and depth for spawners, and extensive sedimentation of gravel. Spawning channel No. 1 was converted into a juvenile rearing facility in 1969.

16. Spawning channel No. 2 succeeded as a chum production facility. Its incubation environment was superior to that in the river. Major modifications in channel No. 2, compared to channel No. 1, included an increased gradient with higher water velocities and a settling basin for silt at the channel inlet.

17. Stream improvement and expansion during 1965 to 1969 succeeded in expanding the total spawning area in the river (excluding spawning channels) from about 33,500 m^2 to approximately 129,300 m^2. The combined 1969 river and channel capacity was approximately 145,000 m^2.

18. Timing of adult migration into the Big Qualicum River was affected by river discharge and (at least for chum) by date of arrival into the estuary.

19. Spawning distribution was apparently affected by stream improvement, with chum concentrating in the lower river reaches and coho and chinook in the upper reaches. Escapement totals and river discharge had no apparent effect on spawning distribution in the river.

20. Freshwater production of Big Qualicum River chum increased with improved flow regime but declined with increased sedimentation and spawner density (the latter was directly related to egg retention and superimposition of redds).

21. Freshwater production of coho, chinook and steelhead was determined more by success during rearing than during incubation. Coho smolt biomass increased with increased minimum summer flows and declined with increased maximum water temperatures; chinook fingerlings showed no such correlation. Intraspecific competition was probably a controlling factor in the production of coho and to a lesser extent of chinook.

22. Marine survival of chum was not related to fry source of origin (river and two channels), fry size, or offshore salinity; but was related to surface ocean temperatures in the first summer and winter of chum marine life.

23. Marine survival to escapement of coho and chinook was not related to migrant size or migration timing; however, at high juvenile production, marine survival of chinook seemed to decline perhaps due to resource limitations. Ocean salinities and temperatures in the first year at sea were not related to coho and chinook marine survivals. Marine survival of steelhead increased for older smolts.

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Appendix 1. Linear regression equations used to convert mid-eye-fork of tail (ME - FT) and postorbital-fork of tail (PO - FT) to postorbital-hypural plate (PO - HYP) length of adult chum, chinook and coho salmon (n gives sample size).

Species	Sex	n	Regression equation	Correlation coefficient
Chum	male	39	(PO-HYP) = 57.27 + 0.80 (ME-FT)	0.89
	female	66	(PO-HYP) = 42.07 + 0.96 (ME-FT)	0.87
	both	105	(PO-HYP) = 10.09 + 0.88 (ME-FT)	0.87
	male	39	(PO-HYP) = 66.36 + 0.80 (PO-FT)	0.89
	female	66	(PO-HYP) = 36.97 + 0.86 (PO-FT)	0.79
	both	105	(PO-HYP) = 62.21 + 0.82 (PO-FT)	0.82
Chinook	male	26	(PO-FT) = -3.828 + 0.991 (ME-FT)	1.00
	female	27	(PO-FT) = -6.131 + 0.994 (ME-FT)	1.00
	both	53	(PO-FT) = -4.785 + 0.992 (ME-FT)	1.00
	male	88	(PO-HYP) = 14.709 + 0.876 (PO-FT)	0.97
	female	113	(PO-HYP) = 2.969 + 0.907 (PO-FT)	0.97
	both	210	(PO-HYP) = 0.646 + 0.906 (PO-FT)	0.99
Coho	male	54	(PO-HYP) = 14.12 + 0.85 (ME-FT)	0.98
	female	52	(PO-HYP) = 8.01 + 0.88 (ME-FT)	0.98
	both	106	(PO-HYP) = 9.42 + 0.87 (ME-FT)	0.97
	male	54	(PO-HYP) = 75.14 + 0.81 (PO-FT)	0.93
	female	52	(PO-HYP) = 21.81 + 0.93 (PO-FT)	0.99
	both	106	(PO-HYP) = 59.17 + 0.85 (PO-FT)	0.94

Appendix 2. Juvenile enumeration techniques.

Each year, an estimate of trapping efficiency of the year, if less than the total flow was strained, was conducted for as many species and trap configurations as possible. This efficiency was measured as the percent recovery of a known number of marked fish released above the traps. When circumstances occasionally prevented a complete range of tests, two approaches were used to obtain estimates for the missing data. One was to use for the particular species and gear type, the mean trapping efficiencies determined in other years. The second approach was used if no efficiency tests were available for a given (unknown) species with a particular gear type, but they were available for another species. To obtain the desired catchability estimate, all the tests on all types of gear in all years when the known and unknown species were run simultaneously were analyzed to determine a catchability ratio for the unknown species relative to the known species. The mean ratio was then applied to the trapping efficiency of the new gear type for the known species to give an estimate for the unknown species. In most cases, any inaccuracies introduced by this method were small because this method was usually employed only at the end or start of the migration period for the unknown species when the traps were arranged to concentrate on other species.

Marking of chum, pink, coho and chinook fry for the catchability tests was done with vital stains. Of the many stains tested, neutral red and Bismark brown yellow (BBY) proved most effective and became the standard marks. The staining procedure involved the immersion of a randomly selected sample of migrating fry (usually 1000-2000) in a solution of the dye (1/80,000 for BBY and 1/200,000 for neutral red). In 1971, the use of dimethyl sulfoxide (DMSO) in conjunction with neutral red was tested. This compound reportedly has low toxicity to salmonids, and increases the penetration of organic and inorganic compounds through biological membranes (Willford 1967). Mixtures of neutral red and DMSO (final concentrations of 1/400,000 and 1/2,000 respectively) gave satisfactory marks after two hours' exposure. This method was used from 1971 onward.

The stained fish were held until dark in a live box immersed in the river about 90 m above the traps. Fish were then released and subsequently scored in the catch. Tests showed that recaptures after the first night were insignificant. However, to ensure that results were unbiassed, the dyes were alternated or, if both dyes were used simultaneously, a lag period of at least one night was allowed before further experiments were performed.

Since and including the 1971 downstream run, the escaped fraction of dyed fry used to test the channel No. 2 gear was scored at the main fence as well, to estimate its trapping efficiency. Prior to this, independent tests were run for each location.

For the larger smolts and fingerlings, partial or complete removal of a fin, usually the upper or lower lobe of the caudal, was more effective than staining. Partial removal of the dorsal and complete removal of the adipose fins were also used. Since complete fin removal is permanent it was generally avoided.

It was often necessary to hold coho and steelhead smolts until sufficient numbers accumulated to conduct a test. These fish tended to remain upstream after being marked causing tests to overlap; therefore the data for smolts were pooled for each season in order to give a more reliable estimate of trap efficiency.

Appendix 3. Juvenile marking techniques.

The fry were marked throughout the downstream migration period and, as far as possible, at a constant percentage mark rate. Up to the 1966 brood, fry destined for marking were taken from the preceding night's catch at the main river or at channel No. 1 weir. After 1967, the mixing of channel No. 2 and river fry above the main fence necessitated that river fry be obtained above the channel No. 2 outlet. This was accomplished using one or two 1.2 m x 1.2 m fyke nets (1968-1970) or four large fan traps (1971 onward) at hub 280. During 1968 to 1970, channel No. 2 fry were captured for marking at the channel No. 2 outlet and, if additional numbers were required, in a 1.2 m x 1.2 m fyke net set 140 m above the outlet. From 1971 onward, all required channel fry were captured by fyke net. These fish were transported in a 10 cm diameter pipe to a live box located above the fence at hub 290 adjacent to the hatchery office. Excess fry not required for marking were counted, then released below the fence the following night.

The fry were held in large floating live boxes, and small batches were subsequently removed to 225 l tubs located outside the marking area. Constant flow was maintained through these tubs. From here the fish were transferred to small sinks with water containing 2-phenoxyethanol (approximately 0.025%, v/v). Water temperature in the anaesthetic and reviving sinks was held at about 6°C by a refrigeration system. Marking was carried out at two locations: the laboratory below the main fence and a building near the main fence. From the marking area, the marked revived fry passed down a pipe to floating live boxes in the river.

Marked fry were checked for total mortality, while mark quality subsamples were obtained from each marker's sink or from live box inside the marking building. The mark quality samples normally consisted of 25 fry. These fish were reanaesthetized and examined under strong light and three times magnification; fin clips were rated as good, partial or miss. This procedure was repeated at least once during every two-hour marking period.

Marked fry were held for release until dark to continue downstream with that night's normal migration.

Appendix 4. Monthly maximum, mean and minimum discharges (m^3/sec) measured near the mouth of Big Qualicum River, 1959–1973.

Month	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973
Jan.	60.9	36.8	90.6	35.7	28.9	22.7	6.5	20.8	24.1	21.2	8.9	7.2	9.4	7.6	25.0
	23.9	7.3	29.4	14.3	9.1	20.1	4.8	18.5	19.7	15.3	8.9	6.2	5.2	7.1	14.3
	9.1	2.8	5.6	5.1	2.0	16.4	4.2	15.9	18.0	9.9	8.9	5.4	3.9	6.9	4.0
Feb.	8.2	28.9	32.0	7.4	56.6	16.6	11.1	19.4	18.0	21.7	11.1	5.9	12.5	9.5	19.6
	4.5	16.0	24.6	5.7	19.0	16.1[a]	8.4	15.5	14.4	16.8	8.9	5.4	11.6	7.5	8.2
	2.7	5.1	13.4	3.4	1.7	15.1	5.1	6.7	8.3	6.7	5.2	5.3	9.4	6.8	5.4
Mar.	10.3	15.2	27.5	7.1	16.4	15.1	11.1	7.5	8.3	6.7	6.0	5.7	11.8	13.2	6.0
	7.8	6.2	13.4	4.4	7.1	9.3[a]	7.5	6.9	7.4	6.6	5.3	5.4	8.3	10.0	5.9
	5.5	3.8	7.7	3.1	2.0	8.8	5.0	6.5	6.8	5.6	5.0	5.1	5.5	8.0	5.8
Apr.	17.9	19.3	10.7	9.1	9.7	8.8	5.3	6.9	7.2	5.5	6.5	6.4	8.2	11.5	5.9
	6.7	12.4	6.2	5.6	7.2	8.3[a]	5.0	6.8	7.2	5.1	5.6	5.2	6.5	8.5	5.0
	3.6	9.0	4.4	4.0	4.3	7.9	4.8	6.7	7.1	4.3	4.9	5.0	4.4	7.1	4.8
May	15.6	8.7	7.1	11.4	6.5	11.0	5.1	6.7	7.1	4.4	8.2	5.0	6.3	6.6	4.8
	6.5	7.0	5.9	5.6	4.2	8.8	4.9	6.0	6.7	4.2	5.7	4.4	5.8	6.4	4.6
	4.4	5.2	4.3	3.1	2.2	7.9	3.7	4.2	4.4	4.2	5.2	2.8	4.4	6.2	3.2
June	4.4	6.6	4.4	4.1	2.1	7.9	3.3	4.2	3.9	4.2	8.2	2.8	5.3	6.3	3.2
	3.3	4.4	3.3	2.9	1.5	4.9	2.4	3.5	3.5	2.7	6.4	2.5	4.8	4.3	2.2
	2.4	2.7	1.9	1.6	1.0	4.2	2.2	3.1	3.5	2.5	4.2	1.6	4.6	2.6	1.7
July	2.3	2.7	1.9	1.8	1.3	4.7	2.2	3.1	3.5	2.5	4.1	2.0	4.7	2.6	1.7
	1.7	1.7	1.2	1.3	1.2	4.0	2.0	3.1	3.5	2.5	4.0	1.6	3.3	1.8	1.7
	1.0	1.1	0.8	1.0	1.0	2.0	1.9	3.1	3.5	2.5	3.8	1.5	2.3	1.6	1.7
Aug.	1.2	1.0	0.8	25.5[b]	1.1	2.1	1.9	3.1	3.5	23.2	7.9	2.2	2.3	1.7	2.0
	1.1	0.8	0.6	5.9	0.9	1.4	1.9	2.7	3.0	6.7	4.8	2.0	2.1	1.6	1.7
	1.0	0.7	0.4	0.9	0.7	0.9	1.7	2.7	2.5	2.1	3.5	2.0	1.9	1.6	1.7
Sept.	1.5	1.0	1.1	25.6[b]	0.8	2.8	4.0	2.7	2.5	14.0	23.8	14.3	22.3	21.6	5.3
	1.2	1.0	0.7	4.8	0.7	1.3	3.7	2.7	2.5	10.8	19.4	5.3	7.3	4.6	2.7
	1.0	0.9	0.5	0.9	0.7	0.9	1.7	2.7	2.4	9.5	7.6	2.0	2.2	1.6	1.8
Oct.	3.7	11.6	6.6	9.3	41.9	7.8	9.1	22.5	11.6	17.1	14.9	8.3	20.6	16.9	23.4
	2.0	3.9	3.3	4.5	12.6	6.6	6.3	8.7	7.1	11.0	10.7	6.1	8.9	4.6	6.9
	1.2	0.8	1.1	1.0	0.9	3.0	3.7	2.7	2.5	9.5	6.6	4.6	7.6	3.7	1.8
Nov.	23.7	23.2	11.9	15.5	26.5	8.2	7.4	8.9	22.8	11.1	9.7	7.5	23.6	5.8	11.7
	7.8	12.1	7.4	7.6	20.3	7.6	6.9	7.4	10.8	8.5	8.1	5.8	14.0	4.2	9.0
	2.8	4.5	4.5	3.7	18.4	6.5	5.1	5.6	6.5	6.4	6.4	4.2	6.0	3.7	7.5
Dec.	38.5	23.6	19.3	37.9	21.7	8.0	18.8	24.1	15.5	10.3	11.6	10.3	9.2	6.5	26.8
	16.7	13.5	10.3	17.7	16.8	6.6	10.7	15.1	8.1	8.7	7.6	4.8	8.0	4.7	17.4
	6.5	6.0	5.3	7.0	13.7	4.8	5.3	6.3	1.5	6.9	7.0	1.9	7.2	3.9	10.7
Yearly	60.9	36.8	90.6	37.9	56.6	22.7	18.8	24.1	24.1	23.2	23.8	14.3	23.6	21.6	26.8
	6.9	7.2	8.9	6.7	8.4	7.9	5.4	8.1	7.8	8.2	7.9	4.6	7.1	5.4	6.7
	1.0	0.7	0.4	0.9	0.7	0.9	1.7	2.7	1.5	2.1	3.5	1.5	1.9	1.6	1.7

[a] Measured at valve house; flows at the mouth may be up to 2.8 m^3/sec. higher.

[b] High flows due to construction activities.

Appendix 5. Proportion of Big Qualicum River monthly flows from sources other than Horne Lake, 1958-1962, 1965-1969.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1958	-	-	-	-	-	23.3	64.1	91.9	51.6	23.1	21.8	60.0
1959	36.7	9.4	14.8	0	5.7	9.6	29.0	73.7	73.9	35.4	25.3	27.2
1960	23.6	12.8	13.2	10.8	13.8	11.7	28.0	63.8	32.1	24.6	22.8	-
1961	23.7	19.4	13.1	14.1	0	19.2	45.5	73.0	64.8	18.8	22.1	20.7
1962	41.7	20.2	32.5	12.7	12.8	25.5	41.1	-	-	-	-	-
Mean	31.4	15.5	15.1	9.4	8.1	17.9	41.5	75.6	55.6	25.5	23.0	36.0
Grand Mean 29.6%												
1965	23.4	19.7	16.6	17.5	16.8	30.1	29.2	27.3	6.9	15.3	18.4	21.2
1966	21.0	17.4	17.3	16.2	14.1	14.6	15.7	19.6	23.2	14.0	21.7	24.4
1967	18.0	12.5	22.5	19.7	18.9	19.2	24.2	25.7	28.7	-	-	-
1968	12.6	11.0	10.3	19.3	14.1	15.5	14.9	16.5	19.2	30.0	36.7	29.6
1969	17.7	17.3	19.9	17.3	16.0	13.2	31.9	21.8	9.8	15.3	34.1	31.3
Mean	18.5	15.6	17.3	18.0	16.0	18.5	23.2	22.2	17.6	18.7	27.7	26.6
Grand Mean 20.0%												

Appendix 6. Monthly maximum and mean temperatures (°C) in Big Qualicum River measured at the camp bridge 1.2 km above the river mouth, 1959–1973.

Month	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	Overall
Jan.	2.8	4.4	6.7	3.6	2.5	4.4	0.6	3.9	3.6	2.2	0.6	2.2	-0.3	0.6	1.7	-0.3
	6.1	6.3	8.9	5.8	6.9	6.7	5.8	5.0	5.3	4.7	3.3	5.0	5.0	3.9	5.0	8.9
	4.8	5.4	7.8	4.8	5.3	5.3	3.2	4.5	4.6	3.4	1.8	4.1	3.2	2.5	3.3	4.3
Feb.	2.8	4.4	6.7	1.7	3.1	3.3	2.8	3.9	3.6	2.5	1.1	3.3	2.8	0.6	1.7	0.6
	5.6	6.3	8.1	6.1	7.8	5.6	4.4	5.6	5.0	5.8	3.3	5.8	5.0	3.9	5.0	8.1
	4.3	5.6	7.3	4.8	6.2	4.5	3.5	4.6	4.2	3.8	2.0	4.5	3.8	2.5	3.4	4.3
Mar.	3.9	3.3	6.4	1.4	5.8	4.2	3.3	3.9	3.3	4.7	1.9	2.8	2.5	2.2	3.3	1.4
	6.7	8.9	9.2	8.6	8.1	7.2	7.2	8.1	6.7	7.8	6.7	8.9	6.7	7.2	7.5	9.2
	5.2	6.1	7.3	4.8	6.8	5.2	4.8	4.7	4.7	5.9	4.0	5.6	4.2	4.4	4.9	5.2
Apr.	5.0	6.1	6.4	5.6	6.1	5.3	4.7	5.3	4.4	5.3	4.4	5.0	4.2	4.2	4.7	4.2
	11.7	11.7	12.2	11.4	12.5	10.3	11.1	10.6	9.4	10.8	8.3	11.1	10.6	9.4	11.1	12.5
	7.6	8.3	8.5	8.1	8.3	7.7	7.6	7.9	6.5	7.4	6.3	7.7	6.4	6.4	7.5	7.5
May	7.8	9.4	9.4	7.2	8.3	7.2	7.2	10.0	3.9	7.2	6.7	7.8	5.6	6.1	6.1	3.9
	14.4	14.2	17.8	16.1	18.1	13.9	16.4	15.0	14.4	16.7	11.4	17.8	11.4	16.7	16.4	18.1
	10.3	10.9	12.4	11.0	11.7	10.4	11.4	12.1	10.7	11.4	8.9	11.8	8.3	10.7	10.8	10.8
June	13.3	11.7	13.9	10.0	11.7	11.7	11.7	12.8	10.6	8.9	7.8	10.8	7.2	10.0	10.0	7.2
	16.7	18.9	20.6	20.0	19.7	17.5	18.9	19.4	18.9	16.7	12.8	20.3	12.5	17.2	18.9	20.6
	14.9	14.1	16.4	14.2	14.6	13.8	14.9	14.1	14.6	12.6	9.9	14.7	9.2	13.0	13.7	13.6
July	-	13.3	12.8	11.4	11.9	13.3	10.6	12.8	11.7	10.3	8.9	11.1	8.9	9.4	9.4	8.9
	-	21.1	17.8	20.6	18.3	18.6	20.0	20.3	19.4	18.9	15.6	20.8	16.4	19.4	20.3	21.1
	-	17.2	15.1	15.2	15.3	15.2	15.4	16.7	15.4	14.2	11.8	14.6	12.2	13.1	14.6	14.7
Aug.	11.7	11.1	11.4	11.1	13.6	12.2	11.7	12.8	11.1	12.2	10.6	10.6	8.9	8.9	8.9	8.9
	17.2	19.4	18.9	18.9	21.4	17.8	18.3	20.6	17.2	18.3	16.4	18.1	16.7	17.5	19.4	21.4
	14.4	14.8	14.7	14.2	17.2	14.6	15.0	15.9	14.4	14.9	12.8	14.3	12.7	12.8	12.9	14.4
Sept.	10.0	9.4	8.3	10.6	10.6	10.0	11.9	12.2	10.6	12.2	11.1	9.2	7.8	8.3	8.9	7.8
	14.4	14.4	14.7	18.9	16.4	15.6	17.5	17.2	17.2	15.6	14.4	15.8	14.2	15.0	15.0	18.9
	12.5	11.8	11.4	13.6	13.6	11.6	15.3	14.2	13.4	14.2	12.1	13.2	11.4	11.8	11.9	12.8
Oct.	9.4	8.9	8.9	7.8	9.2	10.6	10.8	10.0	9.7	10.0	9.7	9.4	9.4	8.3	9.4	7.8
	12.8	12.8	14.4	13.3	14.2	13.9	15.6	15.8	14.4	15.0	13.3	15.6	14.2	13.3	12.2	15.6
	11.4	11.4	11.2	10.2	11.9	12.3	12.7	12.6	11.7	12.5	11.6	12.4	12.7	11.0	11.1	11.8
Nov.	6.7	8.1	5.6	6.9	7.5	6.1	7.2	6.7	6.1	6.7	6.1	5.0	6.7	6.7	5.0	5.0
	11.7	11.7	11.1	10.6	11.7	11.1	11.7	10.6	10.0	10.6	11.1	11.1	10.3	11.1	10.6	11.7
	9.2	9.6	8.2	8.9	9.6	8.7	9.8	8.4	8.4	8.8	8.4	8.6	7.7	8.6	7.4	8.7
Dec.	6.1	7.5	4.2	5.0	5.6	1.7	5.0	5.0	3.9	1.9	4.4	2.8	2.2	3.3	4.2	1.9
	7.8	8.3	7.8	7.8	7.8	8.3	8.6	7.2	6.9	7.8	7.5	6.1	7.8	8.3	6.4	8.6
	7.3	8.0	5.6	6.5	6.8	5.3	6.8	6.0	5.2	5.2	5.9	4.7	4.8	4.8	5.4	5.9

Appendix 7. Horne Lake surface elevations, discharges and surface and outlet water temperatures during summer, 1961-1966, 1969.

Year	Period	Mean surface elevation (m)	Discharge (m^3/sec)	Temperature (°C)	
				Lake outlet	Lake surface
1961	June 1 - Aug. 2	119	2.8-0.8	17.2-23.3	17.8-23.9
	Aug. 2 - Oct. 4	119	0.8	15.6	16.7
	Oct. 4 - Oct. 28	119	1.4	11.1	12.2
1962	June 14 - Aug. 10	119	1.4	16.2-17.8	17.2-18.3
	Aug. 10 - Oct. 5	116	8.5-1.4	14.5	15.6
	Oct. 5 - Oct. 15	116	1.4-8.5	11.6	13.3
1963	June 21 - Aug. 9	119	1.1	16.7-19.4	17.8-21.7
	Aug. 9 - Oct. 4	119	0.8-0.4	16.7	16.7
	Oct. 4 - Oct. 26	119	1.1-19.8	12.2	12.8
1964	June 12 - July 21	111	4.2	13.9-15.6	15.0-16.7
	July 21 - Sept. 28	110	1.7-0.6	15.0	15.6
	Sept. 28 - Oct. 19	109	2.8-7.1	12.2	12.8
1965	June 16 - Aug. 16	111	2.3-2.0	15.6-16.2	16.7-19.4
	Aug. 16 - Oct. 1	110	2.0-4.0	16.2	16.2
	Oct. 1 - Oct. 15	109	4.2-7.1	13.3	13.3
1966	June 14 - Aug. 23	113	3.1-2.5	13.9-17.8	13.9-19.4
	Aug. 23 - Sept. 26	112	2.5	15.0	16.7
	Sept. 26 - Oct. 18	110	2.5-7.6	13.9	13.3
1969	June 12 - Aug. 18	120	4.2-2.0	8.9-12.8	18.3-17.2
	Aug. 18 - Sept. 8	119	4.2-14.2	12.2	17.2
	Sept. 8 - Oct. 15	113	14.2	12.8	13.3

Appendix 8. Difference in mean monthly water temperature at the outlet of Horne Lake and the mouth of Big Qualicum River, 1959-62, 1963-67, 1968-1971.[a]

Year	May	June	July	Aug.	Sept.	Oct.	Nov.
1959	-	-	-	-	4.8	3.7	1.5
1960	-0.5	0.5	3.7	5.3	4.0	2.0	0.1
1961	-1.7	0.3	4.3	6.7	-0.1	2.1	0.6
1962	-0.6	1.6	3.1	4.0	2.7	2.2	0.7
Mean	-0.9	0.8	3.7	5.3	2.9	2.5	0.7
1963	-	1.5	1.4	-0.5	-0.7	0.2	-0.6
1964	-0.1	-0.1	0.7	1.7	2.9	0.6	0.3
1965	0.3	0.5	0.4	0.5	1.4	0.9	0.3
1966	0.1	0.6	0.5	1.1	0.9	0.7	0.8
1967	0.3	1.9	0.8	0.8	1.9	1.9	1.1
Mean	0.2	0.9	0.8	0.7	1.3	1.1	0.4
1968	-0.1	-1.8	-1.8	-0.8	-0.6	-0.3	-0.2
1969	-0.8	-1.1	-1.7	-0.5	0.2	0.7	1.2
1970	-0.9	-1.6	-2.4	-1.7	-0.3	0.5	0.4
1971	-1.5	-1.7	-2.4	-2.7	-0.5	-1.2	-0.2
Mean	-0.8	-1.6	-2.1	-1.4	-0.3	-0.1	0.3

[a] A positive value indicates higher temperature at the lake outlet.

Appendix 9 - The effects of flow control on thermal stratification in Horne Lake and inferences for temperature control in Big Qualicum River.

Efficient temperature control in Big Qualicum River required that cool hypolimnial water from Horne Lake be available to the intakes from June through October. However, even before flow control development, the volume of the hypolimnion was variable. The typical pattern of stratification in Horne Lake was demonstrated by observations in 1963 (Append. Fig. 9-1). A thermocline developed in May, gradually sank to greater depths throughout the summer and early fall, then dissolved by November with re-establishment of isothermal conditions.

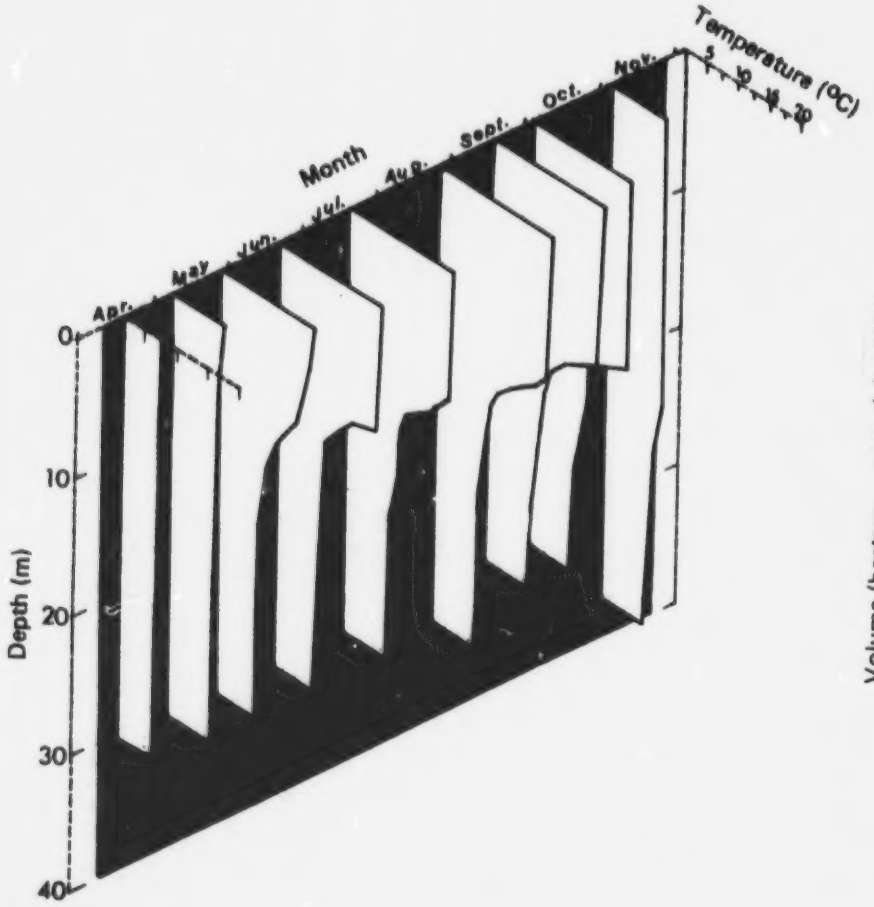
Flow control involved below surface withdrawal resulting in abnormal fluctuations in the lake depth. This introduced the possibility that thermal characteristics of the lake would be altered, thus jeopardizing the quality and quantity of water available to the intakes.

The elevation, but not the depth of the hypolimnion was affected by flow control. During the pre-flow control period (1961-1963), summer surface elevations were approximately 119 m above M.S.L. (Append. 7) with the hypolimnion at a depth of 14 m to 20 m and an elevation of 99 m to 105 m above M.S.L. Early flow control operations (1964-1966) required low lake levels by August 1, and summer surface elevations during this period averaged 109 m to 113 m (Append. 7). The depth of the hypolimnion did not change significantly compared to pre-flow control observations, but its elevation was only 87 m to 97 m (Append. Table 9-1). With lowest intake depth at 94 m elevation and decreasing basin volumes at lower elevations (Append. Fig 9-2, Append. Table 9-1), the availability of cool water for temperature control was zero by August or September (Append. Fig. 9-3, Append. Table 9-1).

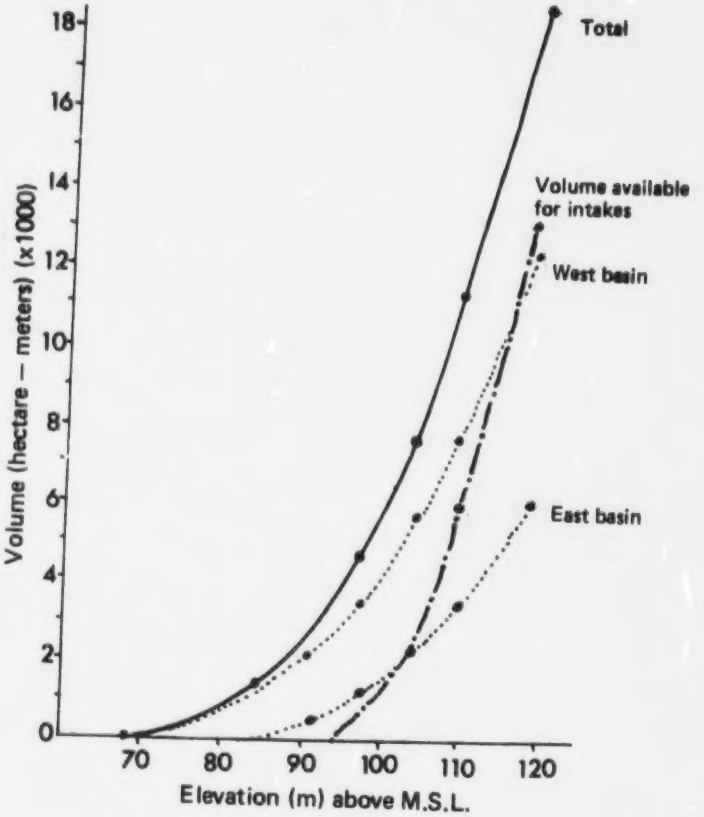
September temperatures were critical for early returning adult salmon, particularly chinook, as was demonstrated by a premature migration of chinook in 1962. Typically, most chinook salmon remained in the estuarial region until early October, leaving saltwater with the first heavy rains (flows of 3.7-6.8 m^3/sec). Temperatures at this time of year were generally 11°C to 13°C. In 1962, between August 18 and September 4, construction work resulted in a release from valves of a controlled high discharge ranging from 8.5 m^3/sec to 25.5 m^3/sec. This was followed by a normal flow (less than 1.1 m^3/sec). During the high discharge period, 450 chinook (57% of total escapement) entered the river. In previous years, migration commenced around mid-September and never exceeded more than 15% of the total run by late September. As a result of the premature migration in 1962, the chinook experienced an eight week holding period prior to spawning in late October. During the first three weeks of this period, mean daily water temperatures were at least 16°C and reached 18.3°C on four days. An estimated 21% of the holding females died unspawned at this time.

The above incident emphasized that survival of chinook adults might require the availability of sufficient hypolimnial water through September and early October (by wich time temperatures normally decline). This requirement was not achieved in the early years of flow control.

Operational amendments from 1968 onward maintained higher summer lake levels which effectively increased the volume of the hypolimnion above the low level intake by an order-of-magnitude (Append. Table 9-1), and permitted temperature control until early October (Append. Fig. 9-3). The advantage (and necessity) of increased summer lake elevations is confirmed when it is considered that the withdrawal ratio of hypolimnial to surface waters was higher in 1969 than in 1964 to 1966, as is apparent from the difference between temperatures in the epilimnion and the lake outlet (Append. 7). Encroachment of the thermocline on the low intake pipe would have occurred even earlier in the summer during 1964 to 1966 under 1969 withdrawal conditions. The revised summer schedule permitted not only the use of more cold water during summer for the benefit of juvenile salmon but also extended the availability of cold water, if necessary, to early returning adults.



Append. Fig. 9—1. Seasonal pattern of thermal stratification in Horne Lake, 1963.

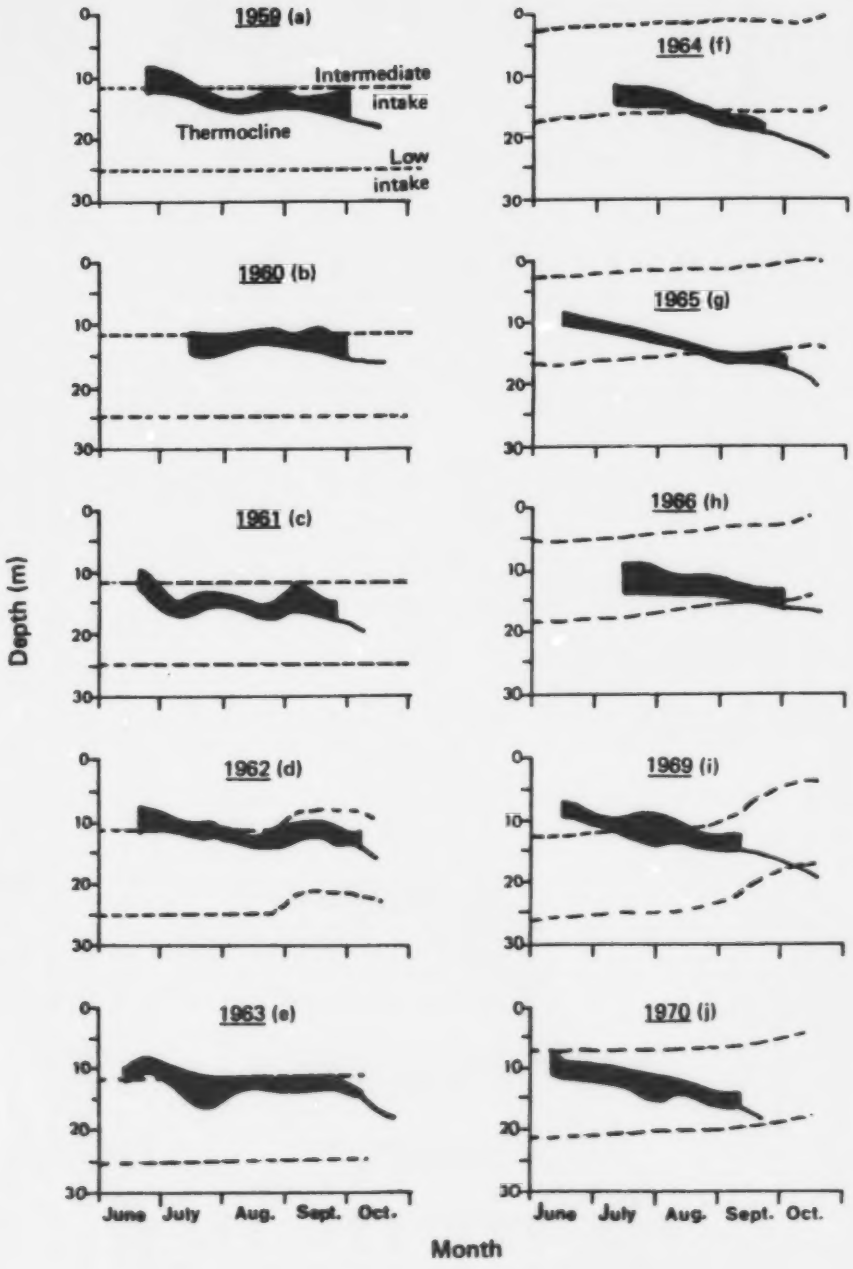


Append. Fig. 9—2. Water volume availability in Horne Lake related to surface lake elevation (refer to Fig.2 for location of east and west lake basins).

Appendix Table 9-1. Horne Lake hypolimnial depth, elevation and volume available to intakes during June through October 1964-1966, 1969.

Year	Period	Mean surface elevation (m)	Mean hypolimnial depth (m)		Mean hypolimnial elevation (m)		Volume available to intakes (hec - m)[a]				
			East	West	East	West	East basin		West basin		Both
							Total	Hypolimnion	Total	Hypolimnion	Hypolimnion
1964	June 12 - July 21	111	15	15	96	96	2,900	200	4,300	0	200
	July 21 - Sept. 28	110	17	15	93	95	2,700	0	3,900	0	0
	Sept 28 - Oct. 19	109	22	18	87	91	2,500	0	3,400	0	0
1965	June 16 - Aug. 16	111	14	17	97	94	2,900	300	4,300	0	300
	Aug. 16 - Oct. 1	110	18	17	92	93	2,700	0	3,900	0	0
	Oct. 1 - Oct. 15	109	20	18	89	91	2,500	0	3,400	0	0
1966	June 14 - Aug. 23	113	17	19	96	94	3,500	200	5,300	0	200
	Aug. 23 - Sept. 26	112	18	18	94	94	3,200	0	4,800	0	0
	Sept 26 - Oct. 18	110	19	-	91	-	2,700	0	3,900	-	-
1969	June 12 - Aug. 18	120	15	15	105	105	5,600	1,700	5,100	1,900	3,600
	Aug. 18 - Sept. 8	119	16	16	103	103	5,300	1,300	4,500	1,200	2,500
	Sept. 8 - Oct. 15	115	19	-	96	-	3,500	0	5,300	-	200

[a] East basin - available water is that above 94 m (low intake elevation).
West basin - available water is that above 99 m (lowest elevation of ridge between the basins).
Both basins - direct summation of available hypolimnial volume in east and west basins assumes lateral transport of water above the ridge meets less physical resistance than vertical circulation from the mixolimnion to the hypolimnion.



Append. Fig. 9–3. Seasonal changes in depth of intermediate and low level intakes in relation to thermocline depth in Horne Lake (1959 – 1961, east basin; 1962 – 1966, 1969, 1970, off intake).

Appendix 10 - Stream improvement in the Big Qualicum River.

The major goals of streambed improvement were as follows:

1. to increase the spawning area;
2. to improve the spawning and egg incubation environment by providing suitable water depths and velocities, and preventing bank erosion and siltation;
3. to maintain or increase fish cover and holding pools for adults and juveniles; and
4. to carry out the improvements without reducing the natural aesthetic quality of the environment.

Stream improvement and expansion works between 1965 and 1969 are summarized in Append. Tables 10-1 to 10-3. Spawning ground expansion between 1964 and 1969 was demonstrated by the survey data obtained in 1964, 1966, 1967 and 1969 (Append. Table 10-4). The spawning area available for each brood stock was estimated from these data and from subsequent improvements (Table 5).

Spawning and incubation environment in compacted sections was improved by adding gravel or loosening compacted materials. Velocity and depth patterns were adjusted at the Horne Lake outlet, and through weir construction and grading along the river. Small side channels were also developed as settling basins for silt.

During the construction of Hunt's Creek flood channel and dyke, the main river was diverted through four man-made channels or relocations (A, B, C & D ; Fig. 4). As a result, four productive river meanders with a high spawning capacity (probably more than 25% of their 22,000 m^2 wetted area) were replaced by straight channels with poor spawning capacity. Improvement of the different relocation areas occurred at different times during 1965 to 1969 (Append. Tables 10 - 1 and 2), and a several fold increase in the proportion of chum spawners using each area always occurred following such improvement work (Append. Table 10-5).

However, despite stream improvement, the relocation areas remained relatively unproductive. Spawning areas in the sections immediately above and below the relocations accomodated approximately 17% of the total chum escapement while the four relocations held only about 7% (Append. Table 10-5). Survey estimates of spawning area in 1969 indicated that the relocations totalled 15,280 m^2 compared to only 8,860 m^2 in the more productive adjacent areas (Append. Table 10-5). Therefore, factors other than space limited spawner density in the relocation areas.

Siltation and compaction which may inhibit spawning, prevent water movement through gravel, and interfere with emergence of alevins, were the expected problems associated with flow control, particularly in a river with a fine sand basin such as the Big Qualicum. With the introduction of flow control measures, it became evident that annual conditioning of the riverbed was required to replace the cleaning action of freshets. In 1969, the entire lower portion of the river from hub 167 downstream (Fig. 4) was graded and reconditioned to suspend silt and loosen the bed material. After grading, discharge was increased to 7.1 m^3/sec for 20 to 24 hours or to 20.7 m^3/sec for 3 to 4 hours to flush the material downstream.

Appendix Table 10-1. Stream improvement activities at Big Qualicum River, 1965-1966.

Year	Site	Activity		Spawning area (m^2)[a]
1964	Downstream from hub 124	Survey.	Total	33,500
1965	Entire study area	Flow reduction (7.1 to 4.2 m^3/sec).		+17,600
	Relocations B & C	Addition of 1900 m^3 of gravel.		+ 3,300
			Total	54,400
		(1964 survey + improvements)		
1966	Relocations B & C			+ 3,000
	Hub 124-148	Log jam removal. Exposed gravel bars spread into river. Rock weir constructed.		+ 2,100
	Hub 238-239	Three rock weirs constructed.		+ 670
			Total	60,200
		(1964 survey + improvements)		
Downstream from hub 124		Survey. (including 1966 expansion)	Total	58,500

[a] Excluding spawning channels No. 1 and No. 2.

Appendix Table 10-2. Chum spawning area inventory (1967) and area expansion (1967, 1968) from Hunt's Creek to hub 281, Big Qualicum River.

Site or hub	Spawning area (m^2) 1967 Survey	Spawning area expansion (m^2) 1967	1968
Hunt's Creek mouth	420	-	290
200-201	430	-	180
201-202	350	-	320
202-203	930	-	490
203-204	1,390	-	210
204-205	1,390	-	210
205-206	1,460	-	280
206-207	1,120	-	170
207-208	950	-	580
208-209	1,020	-	770
209-210	440	-	590
210-211	680	-	250
211-212	660	-	80
212-213	770	-	450
213-214	650	-	-
Relocation A	4,200	8,240	-
222-223	330	930	-
223-224	-	-	-
224-Reloc. B	-	-	-
Relocation B	4,260	870	-
236-237	1,630	-	-
237-238	810	-	1,620
238-239	840	-	1,670
239-240	510	-	280
240-241	800	-	740
241 + Reloc. C	3,450	-	840
245-246	920	970	-
246-247	990	-	740
247-248	940	-	720
248-249	970	290	-
249-Weir	330	-	-
Relocation D	3,340	-	1,670
257-258	670	870	-
258-259	190	60	-
259-260	730	800	-
260-261	470	430	390
261-262	1,080	940	-
262-263	450	270	-
263-264	650	150	-
264-265	400	370	-
265-266	500	460	-
266-267	500	460	-
267-268	660	610	-
268-269	1,090	840	-
269-270	580	440	-
270-271	1,670	500	-
271-272	410	380	-
272-273	280	-	300
273-274	160	40	130
274-275	300	450	-
275-276	890	-	130
276-277	380	-	500
277-278	330	-	250
278-279	320	-	320
279-280	630	-	150
280-281	630	-	-
Total	51,000	19,400	15,300

Appendix Table 10-3. Chum spawning area inventory and improvement activities, Big Qualicum River, 1969.

Hub	Activity or comment	Surveyed spawning area (m^2)	Expansion (m^2)
147-148	Graded, coarse gravel, good grade.	460	460
148-149	Graded, widened, good gravel and grade.	700	0
149-150	DITTO	100	170
	DITTO	280	280
150-151	DITTO	280	1,390
151-152	Extreme compaction.	0	0
152-153	Grade too steep.	0	0
	Weir built, good gravel and gradient.	490	490
153-154	Good gravel and gradient.	280	1,110
154-155	Weir built, good gravel and gradient.	0	2,230
155-156	DITTO	0	1,490
156-157	Good gravel and grade (extreme compaction, siltation).	190	930
	Good gravel and widened side channel.	90	90
157-158	Good gravel and gradient.	190	740
158-159	Good gravel and gradient, near side channel.	0	560
	Good gravel and gradient.	210	630
159-160	Good gravel and gradient, new side channel.	0	280
	Good gravel and gradient, exposed bar spread.	90	460
160-161	DITTO	560	420
161-162	DITTO	840	840
162-163	Good gravel and gradient, new side channel.	0	560
163-164	Good gravel and gradient.	210	350
164-164A	Good gravel and gradient, new side channel.	0	280
164A-165	Good gravel and gradient, (extreme compaction).	280	1,390
165-166	Good gravel and gradient, widened side channel.	190	0
	Good gravel and gradient.	90	460
166-167	Good gravel and gradient, new side channel.	0	350
	Total	5,530	15,960

Total spawning area (hub 147-167) after improvements 21,500 m^2.

Appendix Table 10-4. Summary of chum spawning area surveys at Big Qualicum River, 1964, 1966, 1967, 1969.

1964 (7.1 m^3/sec)[a]		1966[b] (4.2 m^3/sec)[a]		1967[c] (4.2 m^3/sec)[a]		1969[d] (4.2 m^3/sec)[a]	
Site	Spawning area (m^2)	Site	Spawning area (m^2)	Site	Spawning area (m^2)	Site	Spawning area (m^2)
Hub 124-147	3,800[d]	Hub 124-148	8,300			Hub 124-147	8,300[e]
147-174	4,300	148-173	11,500			147-167	21,500
174-200	1,400	173-203	2,900			167-173	5,000
200-214	4,100	203-214	5,700			173-200	840[e]
Relocation A	0						
B	920	Relocation	7,600				
C	1,500	areas					
D	330			200-281	51,000	Hub 200-281	85,300
Sections between relocations	2,300	Sections between relocations	3,500				
Hub 256-281	6,900	Hub 256-284	10,600				
281-290	1,800	284-290	2,300			Hub 281-290	2,300[e]
290-mouth	6,100	290-mouth	6,100[e]			290-mouth	6,100[e]
Total	33,500	Total	58,500			Total	129,300
Spawning channel No. 1	2,800	Spawning channel No. 1	2,800			Spawning channel No. 2	12,000

[a] Discharge during spawning indicated after each year.

[b] Includes 1966 expansion.

[c] Survey details available in Append. Table 10-2; excludes 1967 expansion.

[d] Spawning area hubs 100-124 (5,900 m^2) not included; includes 1969 expansion; survey details available in Append. Table 10-3.

[e] Estimated from previous data.

Appendix Table 10-5. Chum spawner utilization of the relocation areas (R-A, B, C, D) adjacent areas in Big Qualicum River before and after stream improvements, 1962-1971.

	River section and spawning area (1969 survey)					
	Rib 208-214 (4,220m²)	R-A (4,220²)	R-B (4,260m²)	R-C (3,450m²)	R-D (3,350m²)	Rib 257-265 (4,640m²)
	% of escapement utilizing each area					
Pre-improvement period						
1962	4.2	0.09	0.23	0.23	0.05	3.7
1963	10.2	0.52	0.41	0.50	0.22	2.9
1964	0.3	0.06	0.08	0.03	0.12	0.3
1965	2.8	0.11			0.33	2.1
1966	3.3				0.75	4.9
1967	1.9				0.33	
1968					0.61	
Mean (±1 S.D.)	3.8(3.4)	0.20(0.22)	0.24(0.17)	0.25(0.24)	0.34(0.25)	2.8(1.7)
Post-improvement period						
1965			2.3	2.6		
1966		0.44	2.3	2.0		
1967		1.10	1.8	1.8		2.2
1968	5.4	0.34	2.0	2.4		10.3
1969	7.4	0.43	1.7	2.6	1.3	11.8
1970	6.2	0.84	2.9	3.9	2.2	10.2
1971	6.6	0.75	1.2	1.8	1.2	16.9
Mean (±1 S.D.)	6.4(0.8)	0.65(0.30)	2.0(0.3)	2.4(0.7)	1.6(0.6)	10.3(5.3)

Appendix 11. Sex composition of chum adults in Big Qualicum River above hub 290, 1959-1972.[a]

Year	Males (No.)	Females (No.)	Females (%)
1959	1,821	1,875	50.7
1960	1,473	1,314	47.1
1961	1,645	1,988	54.7
1962	2,370	2,397	50.3
1963	3,426	3,627	51.4
1964	2,326	2,401	50.8
1965	6,733	5,512	45.0
1966	2,792	2,650	48.7
1967	4,967	4,735	48.8
1968	22,169	24,091	52.1
1969	18,611	20,027	51.8
1970	20,501	26,655	56.5
1971	7,605	10,500	58.0
1972	2,223	2,370	51.6
Mean ±1 S.D.	-	-	51.3±3.5

[a] All data are from dead pitch samples except in 1965 when fence count sexing was used.

Appendix 12. Age composition of chum adults in Big Qualicum River above hub 290, 1959-1972 (n gives sample size).

Year	n	Age 3 (% of total)			Age 4 (% of total)			Age 5 (% of total)		
		Overall	Males	Female	Overall	Males	Female	Overall	Males	Females
1959	98	34.7	26.5	8.2	64.3	55.1	9.2	1.0	1.0	0.0
1960	130	16.9	10.8	6.2	83.1	34.6	48.5	0.0	0.0	0.0
1961	597	15.1	7.9	7.2	80.9	36.5	44.4	4.0	1.7	2.4
1962	542	84.5	38.4	46.1	15.3	5.7	9.6	0.2	0.0	0.2
1963	993	23.9	15.0	8.9	76.0	33.7	42.3	0.1	0.1	0.0
1964	481	23.7	16.0	7.7	75.5	43.9	31.6	0.8	0.6	0.2
1965	423	51.3	31.4	19.9	45.9	18.4	27.4	2.8	1.7	1.2
1966	699	36.5	20.7	15.7	62.8	28.9	33.9	0.7	0.3	0.4
1967	634	32.5	19.6	12.9	67.0	29.8	37.2	0.5	0.3	0.2
1968	1,164	29.9	16.4	13.5	69.6	30.0	39.6	0.5	0.4	0.1
1969	1,418	47.4	23.1	24.3	49.2	16.2	33.0	3.4	0.9	2.5
1970	1,755	6.6	2.2	4.4	92.5	27.2	65.3	0.9	0.3	0.6
1971	1,997	7.6	4.0	3.6	81.7	41.1	40.6	10.7	6.0	4.7
1972	1,069	16.3	8.6	7.7	75.3	38.5	36.8	8.4	4.7	3.7
Mea ±1 S.D.	-	30.5±20.6	17.2	13.3	67.1±19.6	31.4	35.7	2.4±3.3	1.3	1.1

Appendix 13. Mean (±1 S.D) length of chum adults by age in Big Qualicum River above hub 290, 1959-1972 (n gives sample size).

Year	Age 3 n	Age 3 Length (mm)	Age 4 n	Age 4 Length (mm)	Age 5 n	Age 5 Length (mm)	Age 6 n	Age 6 Length (mm)
1959	34	557 ±24	63	603 ±30	1	581	1,171	581 ±35
1960	22	568 ±22	108	596 ±37	0	-	2,078	585 ±34
1961	90	585 ±30	483	612 ±35	24	622 ±29	750	608 ±35
1962	458	580 ±23	83	613 ±25	1	664	1,130	585 ±27
1963	237	564 ±25	755	602 ±25	1	586	1,885	595 ±32
1964	114	566 ±20	363	604 ±23	4	633 ± 7	965	598 ±28
1965	217	539 ±25	194	583 ±24	12	586 ±37	502	559 ±33
1966	255	557 ±25	439	584 ±27	5	596 ±25	746	574 ±29
1967	206	545 ±28	425	591 ±26	3	595 ±23	697	576 ±35
1968	348	558 ±27	810	581 ±28	6	625 ±41	1,307	574 ±30
1969	672	533 ±30	698	594 ±31	48	604 ±27	1,664	565 ±44
1970	116	539 ±31	1,624	578 ±29	15	603 ±31	1,923	575 ±32
1971	153	534 ±25	1,631	573 ±28	213	590 ±26	2,097	572 ±30
1972	174	540 ±29	805	576 ±25	90	605 ±31	1,139	573 ±31
Mean ±1 S.D.	-	555 ±17	-	592 ±13	-	607 ±23	-	580 ±13

Appendix 14. Mean (±1 S.D) length of chum males by age in Big Qualicum River above hub 290, 1959-1972 (n gives sample size).

Year	Age 3 n	Age 3 Length (mm)	Age 4 n	Age 4 Length (mm)	Age 5 n	Age 5 Length (mm)	All ages n	All ages Length (mm)
1959	26	562 ±17	54	606 ±28	1	581	593	584 ±33
1960	14	569 ±26	45	594 ±31	0	-	1,030	588 ±32
1961	47	588 ±27	218	615 ±27	10	620 ±28	333	609 ±29
1962	208	579 ±24	31	607 ±22	0	-	532	583 ±28
1963	149	564 ±22	335	605 ±25	1	586	879	592 ±32
1964	77	567 ±21	211	605 ±23	3	635 ± 6	324	596 ±29
1965	133	539 ±27	78	584 ±24	7	593 ±41	254	554 ±34
1966	145	556 ±25	202	589 ±27	2	610 ±35	375	576 ±31
1967	124	548 ±30	189	594 ±28	2	608 ±11	349	577 ±37
1968	191	562 ±26	349	590 ±28	5	627 ±46	626	579 ±31
1969	327	528 ±29	230	598 ±34	13	607 ±24	702	558 ±47
1970	38	534 ±25	478	581 ±31	5	609 ±21	544	577 ±33
1971	81	534 ±26	821	580 ±27	120	595 ±28	1,073	578 ±30
1972	92	541 ±29	412	582 ±25	50	613 ±30	572	578 ±32
Mean ±1 S.D.	-	555 ±18	-	595 ±11	-	607 ±16	-	581 ±14

Appendix 15. Mean (±1 S.D) length of chum females by age in Big Qualicum River above hub 290, 1959-1972 (n gives sample size).

Year	Age 3 n	Age 3 Length (mm)	Age 4 n	Age 4 Length (mm)	Age 5 n	Age 5 Length (mm)	All ages n	All ages Length (mm)
1959	8	541 ±35	9	583 ±38	0	-	578	578 ±37
1960	8	567 ±13	63	597 ±40	0	-	1,048	582 ±36
1961	43	582 ±32	265	609 ±40	14	623 ±31	417	607 ±39
1962	250	581 ±23	52	617 ±26	1	664	598	588 ±27
1963	88	563 ±28	420	600 ±25	0	-	1,006	596 ±32
1964	37	562 ±18	152	602 ±24	1	626	641	599 ±28
1965	84	541 ±23	116	582 ±24	5	576 ±34	248	565 ±31
1966	110	557 ±25	237	581 ±26	3	587 ±16	371	573 ±28
1967	82	541 ±24	236	588 ±25	1	570	348	575 ±32
1968	157	552 ±26	461	575 ±27	1	615	681	569 ±29
1969	345	537 ±31	468	593 ±30	35	603 ±29	962	570 ±41
1970	78	542 ±33	1,146	576 ±28	10	600 ±36	1,379	575 ±31
1971	72	534 ±25	810	567 ±27	93	583 ±22	1,427	568 ±28
1972	82	540 ±30	393	571 ±23	40	596 ±30	567	568 ±29
Mean ±1 S.D.	-	553 ±16	-	589 ±15	-	604 ±27	-	579 ±13

Appendix 16. Egg retention of chum in Big Qualicum River above hub 290, 1959-1972 (n gives sample size).

Brood year	n	Mean length of females (mm)	Mean fecundity (eggs/female)	Projected egg content	No. eggs retained	Egg retention (%)
1959	103	577	2,990	307,970	79,422	25.79
1960	532	579	3,063	1,629,516	146,443	8.99
1961	223	607	3,226	719,398	51,966	7.22
1962	474	588	3,217	1,524,858	109,824	7.20
1963	965	597	3,264	3,149,760	210,375	6.68
1964	639	599	3,076	1,965,673	47,411	2.41
1965	248	565	2,708	671,584	11,800	1.76
1966	365	573	2,795	1,020,025	12,210	1.20
1967	386	573	2,795	1,078,712	13,609	1.26
1968	623	568	3,328	2,073,444	54,286	2.62
1969	440	569	3,296	1,450,309	11,991	0.83
1970	901	570	3,065	2,761,295	185,339	6.71
1971	1,049	565	3,013	3,167,351	326,040	10.29
1972	607	568	3,063	1,859,192	287,630	15.47
Mean ±1 S.D.	-	-	-	-	-	7.03 ± 6.87

Appendix 17. Egg deposition of chum in Big Qualicum River above hub 290, 1959-1972.

Brood year	Spawners (No.)	Females (%)	Females (No.)	Mean length of females (mm)[a]	Mean fecundity[b] (eggs/female)	Potential egg deposition (millions)	Egg retention (%)	Actual egg deposition (millions)
1959	83,500	50.7	42,335	578	3,002	127.10	25.80	94.30
1960	47,429	47.1	22,339	582	3,102	69.29	8.99	63.06
1961	10,421	54.7	5,700	607	3,226	18.39	7.22	17.06
1962	34,921	50.3	17,565	588	3,117	56.50	7.20	52.43
1963	27,897	51.4	14,339	596	3,253	46.64	6.68	43.53
1964	24,739	50.8	12,567	599	3,076	38.66	2.41	37.73
1965	12,252	45.0	5,513	565	2,708	14.93	1.76	14.67
1966	43,611	48.7	21,239	573	2,795	59.35	1.20	58.64
1967	20,604	48.8	10,055	575	2,816	28.32	1.26	27.96
1968	102,381	52.1	53,341	569	3,335	177.90	2.62	173.20
1969	64,593	51.8	33,459	570	3,303	110.50	0.83	109.60
1970	82,930	56.5	46,855	575	3,114	145.90	6.71	136.10
1971	64,905	58.0	37,645	568	3,058	115.10	10.30	103.30
1972	36,079	51.6	18,617	568	3,063	57.02	15.50	48.18
Mean ±1 S.D.	-	-	-	-	3,069±189	76.11±50.57	7.03±6.87	70.0±46.9

[a] See Append. 15.

[b] From fecundity - length regression curve.

Appendix 18. Goodness of fit of fecundity (y) to length (x) data (1959 sample) using a variety of curve types.

Curve type	Index of determination
$y = A + Bx$	0.495
$y = Ae^{Bx}$	0.491
$y = Ax^{B}$	0.508
$y = A + B/x$	0.509
$y = 1/ (A + Bx)$	0.417
$y = x/ (A + Bx)$	0.467

Appendix 19. Linear regression analysis of chum fecundity (y) on length (x) where y = bx + a, Big Qualicum River, 1959-1972 (n gives sample size).

Year	n	Mean female length (mm)[a]	Mean fecundity	Intercept (a)	Slope (b)	Correlation coefficient[b]
1959	30	582	3,078	-3,807	11.78	0.70**
1960	25	599	3,325	-4,470	13.01	0.73**
1961	22	630	3,512	-4,289	12.38	0.75**
1962	49	590	3,257	-6,656	16.79	0.79**
1963	39	594	3,233	-3,196	10.82	0.63**
1968	58	582	3,424	- 574	6.87	0.37**
1969	52	573	3,323	- 670	6.97	0.45**
1970	77	593	3,290	-2,584	9.91	0.40**
1971	77	571	3,095	-4,303	12.96	0.67**
1972	100	577	3,121	- 595	6.44	0.30**

[a] Post-orbital hypural.

[b] ** $p < 0.01$.

Appendix 20. Egg deposition of chum in Big Qualicum River above hub 290, 1959-1972.

Brood year	Spawners (No.)	Females[a] (%)	Females (No.)	Mean fecundity[a] (eggs/female)	Potential egg deposition (millions)	Egg retention[a] (%)	Actual egg deposition (millions)
1959	15,000	50.7	7,605	3,002	22.83	25.80	16.94
1960	12,500	47.1	5,888	3,102	18.26	8.99	16.62
1961	3,354	54.7	1,835	3,226	5.92	7.22	5.49
1962	12,220	50.3	6,147	3,117	19.16	7.20	17.78
1963	7,692	51.4	3,954	3,253	12.86	6.68	12.00
1964	10,269	50.8	5,217	3,076	16.05	2.41	15.66
1965	4,385	45.0	1,973	2,708	5.34	1.76	5.25
1966	7,692	48.7	3,746	2,795	10.47	1.20	10.34
1967	13,738	48.8	6,704	2,816	18.88	1.26	18.64
1968	22,246	52.1	11,590	3,335	38.65	2.62	37.64
1969	19,208	51.8	9,950	3,303	32.86	0.83	32.59
1970	26,769	56.5	15,124	3,114	47.10	6.71	43.94
1971	24,074	58.0	13,963	3,058	42.70	10.30	38.30
1972	25,173	51.6	12,989	3,063	39.79	15.50	33.62
Mean ±1 S.D.	-	-	-	3,069±195	23.6±14.0	7.03±6.87	21.77±12.86

[a] Comparable upper river data.

Appendix 21. Mean (±1 S.D.) length, weight, condition coefficient and migration timing of chum fry in Big Qualicum River above hub 290, 1959-1972 broods (n gives sample size).

Brood year	n	Length[a] (mm)	Weight[a] (mg)	Condition coefficient[b]	Migration timing			
					Start	50%	End	Duration (days)
1959	-	-	-	-	Mar. 20	May 6	June 3	75
1960	910	38.9±2.0	-	-	Mar. 19	May 5	June 19	92
1961	500	39.9±1.4	-	-	Mar. 2	May 1	June 23	113
1962	1,989	39.2±1.4	400[c]	0.663[c]	Mar. 11	May 1	June 20	101
1963	1,561	37.2±2.8	380±20	0.745	Mar. 2	May 6	June 27	117
1964	1,322	39.2±1.6	370±50	0.612	Mar. 11	May 18	June 20	101
1965	1,660	39.4±1.7	350±40	0.566	Mar. 16	May 7	July 2	108
1966	1,142	39.0±1.5	350±40	0.587	Feb. 25	May 9	June 16	111
1967	630	38.9±1.4	350±40	0.596	Mar. 14	May 12	July 8	116
1968	2,381	38.8±1.5	350±40	0.594	Mar. 23	May 27	July 18	117
1969	4,930	38.9±1.7	350±40	0.594	Mar. 6	May 6	July 13	139
1970	11,539	39.2±1.6	360±50	0.632	Mar. 25	June 7	Aug. 6	134
1971	2,340	38.2±1.6	330±40	0.591	Mar. 6	May 21	June 29	115
1972	2,700	38.9±1.5	350±40	0.588	Mar. 1	May 3	June 15	107
Mean ±1 S.D.	-	38.9±0.6	358±19	0.615±.050	Mar. 11±9	May 11±11	June 29±16	110±16

[a] Lengths, weights and condition coefficients are brood means calculated by weighting daily samples by daily migrant totals.

[b] Condition coefficient = weight (mg) x 100/length $(mm)^3$.

[c] Weight measurements on 1962 brood were for 16 groups of fry; in other years individuals were measured.

Appendix 22. Chum fry production (millions) in different areas of the Big Qualicum River system, 1959-1972 (top numbers identify columns).

Brood year	1 Hub 290	2 Hub 280	3 Channel No. 2 fence	4 Channel No. 2 fyke net (excluding fish for marking)	5 Channel No. 2 fence (catch released below Hub 290)	6 Channel No. 2 fish marked	7 Channel No. 2 total production (3+4+6)	8 Main river above hub 290 production (1+2+5-3)	9 Channel No. 1 production	10 Main river below hub 290 production[a]	11 System production (7+8+9+10)
1959	17.9	0	0	0	0	0	0	17.9	0	3.22	21.1
1960	3.61	0	0	0	0	0	0	3.6	0	0.95	4.6
1961	3.44	0	0	0	0	0	0	3.4	0	1.11	4.6
1962	5.14	0	0	0	0	0	0	5.1	0	1.74	6.9
1963	15.0	0	0	0	0	0	0	15.0	1.78	4.15	20.9
1964	10.8	0	0	0	0	0	0	10.8	0.10	4.46	15.4
1965	7.06	0	0	0	0	0	0	7.1	0.69	2.52	10.3
1966	17.6	0	0	0	0	0	0	17.6	1.14	3.10	21.8
1967	22.4	0.41	11.1	0.21	1.21	0.39	11.7	13.0	0.56	8.69	34.0
1968	39.6	3.33	15.2	1.95	0.75	0.45	17.6	28.4	0	6.17	52.2
1969	48.1	3.92	18.5	1.71	0	0.69	20.9	33.6	0	10.00	64.5
1970	36.4	3.01	18.5	1.27	0	0.68	20.4	20.9	0	6.77	48.1
1971	29.0	0	15.1	1.43	0	1.00	17.5	14.0	0	5.17	36.7
1972	32.6	0	19.6	1.86	0	1.00	22.5	12.9	0	9.04	44.4

[a] Assumes length-fecundity regressions and egg-to-fry survival values for main river below hub 290 are the same as those above hub 290.

Appendix 23. Chum fry downstream totals from different areas of the Big Qualicum River system, adjusted for losses, 1959–1972.

Brood year	Adjustments[a] (millions)				Downstream totals (millions)					
	Main river above hub 290	Main river below hub 290	Channel No. 1	Channel No. 2	Main river above hub 290	Main river below hub 290	Channel No. 1	Channel No. 2	Freshwater reared[b]	System total
1959	0	0	0	0	17.9	3.2	0	0	0	21.1
1960	0	0	0	0	3.6	0.95	0	0	0	4.6
1961	0	0	0	0	3.4	1.1	0	0	0	4.6
1962	0	0	0	0	5.1	1.7	0	0	0	6.9
1963	0	0	0	0	15.0	4.2	1.78	0	0	20.9
1964	0	0	0	0	10.8	4.5	0.10	0	0	15.4
1965	~ 0[c]	0	~ 0[c]	0	7.1	2.5	0.69	0	0	10.3
1966	~ 0[c]	0	~ 0[c]	0	17.6	3.1	1.14	0	0	21.8
1967	0.1	0	0	0.1	12.9	8.7	0.56	11.6	0.18	33.9
1968	0.3	0	0	2.3	28.1	6.2	0	15.3	2.09	51.7
1969	1.6	0	0	1.4	32.0	10.0	0	19.5	1.60	63.1
1970	~ 0[c]	0	0	~ 0[c]	20.9	6.8	0	20.4	0	48.1
1971	0	0	0	~ 0[c]	14.0	5.2	0	17.5	0	36.7
1972	0	0	0	0.8	12.9	9.0	0	21.7	0	43.6

[a] Adjustments to chum fry production (Append. 22) include fry transferred for freshwater rearing or killed during trapping and marking.

[b] Freshwater reared fish include fry inputs from the main river, channel No. 2 and the hatchery corrected for mortality during incubation.

[c] Negligible.

Appendix 24. Sex composition of chum adults in spawning channel No. 1, 1963-1966, 1969.[a]

Year	Males (No.)	Females (No.)	Females (%)
1963	582	922	61.3
1964	782	758	49.2
1965	1,213	1,065	46.8
1966	1,156	1,383	54.5
1969	190	264	58.1
Mean ±1 S.D.	-	-	54.0±6.0

[a] All data from dead pitch samples.

Appendix 25. Age composition of chum adults in spawning channel No. 1, 1964, 1965 (n gives sample size).

		Age 3 (% of total)			Age 4 (% of total)			Age 5 (% of total)		
Year	n	Overall	Males	Females	Overall	Males	Females	Overall	Males	Females
1964	86	23.3	16.3	7.0	75.6	36.1	39.5	1.2	1.2	0.0
1965	271	46.8	8.5	38.3	52.8	10.0	42.8	0.4	0.0	0.4
Mean		35.1	12.4	22.7	64.2	23.1	41.1	0.8	0.6	0.2
±1 S.D.		±16.6			±16.1			±0.6		

Appendix 26. Mean (±1 S.D.) length of chum adults by age and sex in spawning channel No. 1, 1963-1966, 1969 (n gives sample size).

		Age 3		Age 4		Age 5		All ages	
Year	Sex	n	Length (mm)	n	Length (mm)	n	Length (mm)	n	Length (mm)
1963	Both	-	- -	-	- -	-	- -	434	596±29
1964		20	569±29	65	608±27	1	606 -	224	602±29
1965		127	540±27	143	585±27	1	591 -	304	563±35
1966		-	- -	-	- -	-	- -	523	580±29
1969		-	- -	-	- -	-	- -	264	569±37
Mean ±1 S.D.		-	555±21	-	597±16	-	599±11	-	582±17
1963	Male	-	- -	-	- -	-	- -	-	- -
1964		14	565±22	31	608±27	1	606 -	55	597±32
1965		23	543±28	27	588±31	0	- -	50	567±37
1966		-	- -	-	- -	-	- -	-	- -
1969		-	- -	-	- -	-	- -	-	- -
Mean ±1 S.D.		-	554±16	-	598±14	-	606 -	-	582±21
1963	Female	-	- -	-	- -	-	- -	434	596±29
1964		6	580±42	34	609±27	0	- -	169	604±28
1965		104	540±27	116	585±26	1	591 -	254	562±35
1966		-	- -	-	- -	-	- -	523	580±29
1969		-	- -	-	- -	-	- -	264	569±37
Mean ±1 S.D.		-	560±28	-	597±17	-	591	-	582±17

Appendix 27. Egg retention of chum in spawning channel No. 1, 1963-1966, 1969 (n gives sample size).

Brood year	n	Mean length (mm)	Mean fecundity (eggs/female)	Projected egg content	No. eggs retained	Egg retention (%)
1963	433	596	3,253	1,391,610	141,129	10.1
1964	169	604	3,130	529,024	176,144	33.3
1965	254	562	2,675	679,567	12,642	1.86
1966	522	580	2,870	1,498,349	295,005	19.7
1969	263	569	3,296	866,830	222,365	25.7
Mean ±1 S.D.	-	-	-	-	-	18.1±12.4

Appendix 28. Egg deposition of chum in spawning channel No. 1, 1963-1967, 1969.

Brood Year	Spawners (No.)	Females (%)	Females (No.)	Mean length of females (mm)	Mean fecundity (eggs/female)	Potential egg deposition	Egg retention (%)	Actual egg deposition
1963	2,092	61.3	1,282	596	3,253	4.170	10.1	3.749
1964	1,540	49.2	758	604	3,130	2.373	33.3	1.583
1965	2,278	46.8	1,066	562	2,675	2.852	1.9	2.799
1966	2,540	54.5	1,384	580	2,870	3.973	19.7	3.190
1967	607	48.8[a]	296	575[a]	2,816	0.834	18.1[b]	0.683
1969	454	58.1	264	569	3,296	0.870	25.7	0.647
Mean ±1 S.D. (all years)	-	-	-	-	-	-	18.1±11.1	2.108±1.326
Mean ±1 S.D. (1963-1966)	-	-	-	-	-	-	16.2±13.5	2.830±0.918

[a] Comparable river figure.

[b] Mean of other years.

Appendix 29. Mean (±1 S.D.) length, weight, condition coefficient and migration timing of chum fry in spawning channel No. 1, 1963-1966, 1967 broods (n gives sample size).

Brood year	Fry				Migration timing			
	n	Length (mm)	Weight (mg)	Condition coefficient	Start	50%	End	Duration (days)
1963	1,616	38.4±1.7	350±29	0.618	Mar. 30	May 8	June 5	67
1964	559	39.8±2.3	410±89	0.650	Apr. 25	May 22	June 19	55
1965	1,574	38.9±2.0	360±69	0.612	Apr. 3	May 6	June 12	70
1966	402	39.0±1.5	340±40	0.573	Apr. 19	May 13	May 27	38
1967	252	39.0±1.2	340±39	0.573	Apr. 1	May 19	May 29	58
Mean ±1 S.D.	-	39.0±0.5	360±29	0.605±.03	Apr. 9±12	May 14±7	June 6±10	58±13

Appendix 30. Sex composition of chum adults in spawning channel No. 2, 1967-1972.[a]

Year	Males (No.)	Females (No.)	Females (%)
1967	3,644	4,536	55.5
1968	8,343	6,458	43.6
1969	7,903	8,728	52.5
1970	8,871	11,415	56.3[b]
1971	7,800	9,237	54.2
1972	7,464	11,597	60.8
Mean ±1 S.D.	-	-	53.8±5.7

[a] All data from dead pitch samples.

[b] Due to selective removal of males, females accounted for 58.7% of the population during spawning.

Appendix 31. Age composition of chum adults in spawning channel No. 2, 1967 - 1972 (n gives sample size).

Year	n	Age 3 (% of total)			Age 4 (% of total)			Age 5 (% of total)		
		Overall	Males	Females	Overall	Males	Females	Overall	Males	Females
1967	474	22.8	15.4	7.4	76.0	34.2	41.8	1.2	1.0	0.2
1968	349	26.1	16.6	9.5	73.9	33.5	40.4	0.0	0.0	0.0
1969	341	57.2	31.4	25.8	39.6	17.9	21.7	3.2	2.0	1.2
1970	1,578	7.6	3.0	4.6	91.8	22.7	69.1	0.6	0.3	0.3
1971	1,419	18.7	9.6	9.1	76.1	37.8	38.3	5.2	3.0	2.2
1972	896	10.7	6.7	4.0	83.2	40.5	42.6	6.1	3.1	3.0
Mean ±1 S.D.	-	23.9±17.8	13.8±10.0	10.1±8.0	73.4±17.8	31.1±8.9	42.3±15.2	2.7±2.5	1.6±1.3	1.1±1.2

Appendix 32. Mean (±1 S.D.) length of chum adults by age and sex in spawning channel No. 2, 1967-1972 (n gives sample size).

Year	Sex	Age 3 n	Age 3 Length (mm)	Age 4 n	Age 4 Length (mm)	Age 5 n	Age 5 Length (mm)	All ages n	All ages Length (mm)
1967	Both	108	549±29	360	591±25	6	596±45	500	581±31
1968		91	561±25	258	578±25	0	-	400	573±26
1969		195	532±29	135	586±26	11	604±36	400	557±39
1970		120	544±27	1,449	578±27	9	624±34	1,625	576±29
1971		265	533±26	1,080	568±24	74	581±27	1,491	562±29
1972		96	541±27	745	576±26	55	601±24	958	574±29
Mean ±1 S.D.		-	543±11	-	580±8	-	601±16	-	571±9
1967	Male	73	552±30	162	596±25	5	590±48	250	583±34
1968		58	565±23	117	584±24	0	-	200	576±25
1969		107	534±31	61	593±26	7	609±37	200	558±41
1970		47	539±31	358	584±28	4	633±52	425	579±32
1971		136	532±28	536	571±26	43	586±30	758	564±31
1972		60	542±29	363	580±27	28	605±23	485	577±31
Mean ±1 S.D.		-	544±12	-	585±9	-	605±17	-	573±10
1967	Female	35	543±26	198	588±24	1	625	250	580±28
1968		33	555±27	141	572±25	0	-	200	569±25
1969		88	529±26	74	580±25	4	594±38	200	556±36
1970		73	546±25	1,091	576±26	5	618±14	1,200	575±27
1971		129	534±24	544	566±22	31	573±21	733	560±26
1972		36	540±24	382	572±24	27	596±24	473	571±27
Mean ±1 S.D.		-	541±9	-	576±8	-	601±21	-	569±9

Appendix 33. Egg retention of chum in spawning channel No. 2, 1967-1972 (n gives sample size).

Brood year	n	Mean length (mm)	Mean fecundity (eggs/female)	Projected egg content	No. eggs retained	Egg retention (%)
1967	250	580	2,870	717,600	11,117	1.55
1968	199	569	3,335	663,671	26,289	3.96
1969	199	556	3,205	637,859	15,999	2.51
1970	1,200	575	3,114	3,737,100	339,850	9.09
1971	773	560	2,955	2,293,924	277,035	12.08
1972	559	571	3,082	1,722,972	104,350	6.06
Mean	-	-	-	-	-	5.88±4.07
±1 S.D.						

Appendix 34. Egg deposition of chum in spawning channel No. 2, 1967-1972.

Brood year	Spawners (No.)	Females (%)	Females (No.)	Mean length of females (mm)	Mean fecundity (eggs/female)	Potential egg deposition (millions)	Egg retention (%)	Actual egg deposition (millions)
1967	8,266	55.5	4,588	580	2,870	13.17	1.55	12.97
1968	15,757	43.6	6,870	569	3,335	22.91	3.96	22.00
1969	16,641	52.5	8,737	556	3,205	28.00	2.51	27.30
1970	20,286	58.7	11,908	575	3,114	37.08	9.09	33.71
1971	17,037	54.2	9,234	560	2,955	27.28	12.10	23.98
1972	19,061	60.8	11,589	571	3,082	35.72	6.06	33.56
Mean	-	-	-	-	-	-	5.88±4.07	25.59±7.84
±1 S.D.								

Appendix 35. Mean (±1 S.D.) length, weight, condition coefficient and migration timing of chum fry in spawning channel No. 2, 1967-1972 broods (n gives sample size).

Brood year	n	Length (mm)	Weight (mg)	Condition coefficient	Migration timing			
					Start	50%	End	Duration (days)
1967	842	39.3±1.3	360±40	0.585	Mar. 16	May 14	May 30	75
1968	1,099	38.7±1.6	350±40	0.601	Apr. 18	May 19	June 5	48
1969	3,007	39.0±1.3	350±40	0.599	Mar. 6	May 5	June 9	95
1970	6,228	38.4±1.5	350±40	0.596	Mar. 31	May 31	June 30	91
1971	1,879	38.5±1.5	340±40	0.594	Apr. 7	May 24	June 15	69
1972	1,600	38.2±1.6	330±40	0.599	Mar. 27	May 18	May 30	64
Mean ±1 S.D.		38.7±0.4	350±10	0.596±.006	Mar. 26±13	May 19±9	June 10±12	74±18

Appendix 36 - Assignment of escaping chum adults to brood year and source of origin.

Data and calculations showing the assignment of chum escapements to brood year and source of origin are available in the DFO, Big Qualicum River file No. 5903-85-Q5-d.

Until 1966, all returning chum were of river origin and adults were assigned to the 1959 to 1962 broods on the basis of dead pitch samples taken during 1962 to 1967. In later years, either dead pitch sampling or live sampling at the fence was performed (but both methods were used in 1970 to 1973). When data of both types were available they were used independently since mark recoveries from the two methods did not always coincide.

Until 1971, large numbers of fish were examined for marks, but sample size was later reduced due to budget limitations. Actual mark counts were extrapolated to totals in the escapement and divided into age classes based on scale analysis of subsamples for each mark type. Age composition for the total run was calculated by weighting the age composition of each mark type (including unmarked fish) by the relative abundance of mark types.

The age composition analysis permitted assignment of adults to brood but the source of fry origin after the introduction of channel No. 1 remained unknown. To handle this problem, the data from the 1965 to 1970 broods for which assignment to source of origin was possible, were allowed to represent a two component system where all fish were considered to have originated in the spawning channel or the river. The analytical method was developed from the simple relationship which states that the marked to unmarked ratio of adults is similar to that for juveniles with adjustment for mark mortality (M):

$$\text{Unmarked Adults} = \frac{\text{Marked Adults} \times \text{Total Fry Downstream}}{\text{Effectively Marked Juveniles} \times (1-M)} \qquad (E1)$$

It is difficult to obtain a good estimate for M. If, in considering only the two components, that is AdLV - and AdRV - marked river and channel fish, mark mortality is assumed to be equal, the calculations may be simplified. Two relationships analogous to the above equation (E1) may be constructed - one for river and one for channel fish. Division of the river equation by the channel equation yields a method to compute the ratio of channel to river fish in the escapement (or the catch) and the unknown factor M cancels out. The working equation becomes:

$$\frac{\text{Escapement of River Fish}}{\text{Escapement of Channel Fish}} = \frac{\text{River Marks in Escapement}}{\text{Channel Marks in Escapement}} \times \frac{\text{River Fry Downstream}}{\text{Channel Fry Downstream}} \times \frac{\text{Channel Fry Effectively Marked}}{\text{River Fry Effectively Marked}} \qquad (E2)$$

This ratio was calculated for each age class of each differentially marked brood (1965-1970) using dead and live recovery data when available.

Escapements of river and channel adults for broods represented by AdLV and AdRV fin clips were assigned to source of origin using the above ratios. However, prior to these calculations, it was necessary to remove the freshwater-reared component (Fraser et al. unpublished MS) from the total escapements. The numbers of AdAn-marked chum salmon escaping to the river at different ages were

Appendix 35. Mean (±1 S.D.) length, weight, condition coefficient and migration timing of chum fry in spawning channel No. 2, 1967-1972 broods (n gives sample size).

Brood year	n	Length (mm)	Weight (mg)	Condition coefficient	Migration timing			
					Start	50%	End	Duration (days)
1967	842	39.3±1.3	360±40	0.585	Mar. 16	May 14	May 30	75
1968	1,099	38.7±1.6	350±40	0.601	Apr. 18	May 19	June 5	48
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1970	6,228	38.4±1.5	350±40	0.596	Mar. 31	May 31	June 30	91
1971	1,879	38.5±1.5	340±40	0.594	Apr. 7	May 24	June 15	69
1972	1,600	38.2±1.6	330±40	0.599	Mar. 27	May 18	May 30	64
Mean ±1 S.D.		38.7±0.4	350±10	0.596±.006	Mar. 26±13	May 19±9	June 10±12	74±18

Appendix 36 - Assignment of escaping chum adults to brood year and source of origin.

Data and calculations showing the assignment of chum escapements to brood year and source of origin are available in the DFO, Big Qualicum River file No. 5903-85-Q5-d.

Until 1966, all returning chum were of river origin and adults were assigned to the 1959 to 1962 broods on the basis of dead pitch samples taken during 1962 to 1967. In later years, either dead pitch sampling or live sampling at the fence was performed (but both methods were used in 1970 to 1973). When data of both types were available they were used independently since mark recoveries from the two methods did not always coincide.

Until 1971, large numbers of fish were examined for marks, but sample size was later reduced due to budget limitations. Actual mark counts were extrapolated to totals in the escapement and divided into age classes based on scale analysis of subsamples for each mark type. Age composition for the total run was calculated by weighting the age composition of each mark type (including unmarked fish) by the relative abundance of mark types.

The age composition analysis permitted assignment of adults to brood but the source of fry origin after the introduction of channel No. 1 remained unknown. To handle this problem, the data from the 1965 to 1970 broods for which assignment to source of origin was possible, were allowed to represent a two component system where all fish were considered to have originated in the spawning channel or the river. The analytical method was developed from the simple relationship which states that the marked to unmarked ratio of adults is similar to that for juveniles with adjustment for mark mortality (M):

$$\text{Unmarked Adults} = \frac{\text{Marked Adults} \times \text{Total Fry Downstream}}{\text{Effectively Marked Juveniles} \times (1-M)} \qquad \text{(E1)}$$

It is difficult to obtain a good estimate for M. If, in considering only the two components, that is AdLV - and AdRV - marked river and channel fish, mark mortality is assumed to be equal, the calculations may be simplified. Two relationships analogous to the above equation (E1) may be constructed - one for river and one for channel fish. Division of the river equation by the channel equation yields a method to compute the ratio of channel to river fish in the escapement (or the catch) and the unknown factor M cancels out. The working equation becomes:

$$\frac{\text{Escapement of River Fish}}{\text{Escapement of Channel Fish}} = \frac{\text{River Marks in Escapement}}{\text{Channel Marks in Escapement}} \times \frac{\text{River Fry Downstream}}{\text{Channel Fry Downstream}} \times \frac{\text{Channel Fry Effectively Marked}}{\text{River Fry Effectively Marked}} \qquad \text{(E2)}$$

This ratio was calculated for each age class of each differentially marked brood (1965-1970) using dead and live recovery data when available.

Escapements of river and channel adults for broods represented by AdLV and AdRV fin clips were assigned to source of origin using the above ratios. However, prior to these calculations, it was necessary to remove the freshwater-reared component (Fraser et al. unpublished MS) from the total escapements. The numbers of AdAn-marked chum salmon escaping to the river at different ages were

extrapolated to unmarked, reared fish using equation (E1). For this computation, removal of both the adipose and anal fins was assumed to cause 20% mortality (M=0.20). Unfortunately, it was not possible to calculate escapement for the Ad-marked, reared fish from the 1967 and 1968 broods. This was due to the small number of fry marked and the background noise arising from natural occurrence of missing fins and regeneration of ventral fins on double-clipped fish. Both live and dead adult sample data for AdAn marks were available for some years. However, only the live sample data were used since only they were obtained in 1974, the year in which age 5 fish from the last reared brood were expected. The estimates of the reared component were subtracted from the system escapement at each age, each year, in order to separate the river plus channel component.

River and channel fry were not differentially marked in the 1963 and 1964 broods, nor in the 1971 and 1972 broods, making it impossible to determine directly the source of escaping adults. Relative survivals of river to channel No. 1 broods (1965 - 1966) and of river to channel No. 2 broods (1967 - 1970) were available and these data were used to calculate the expected ratios of returns from the 1963, 1964, 1971 and 1972 broods. Breakdown to source of origin of the escapements involving these broods were calculated whenever possible using both dead and live sample data.

In 1968, channel No. 1 produced 564,000 chum fry but these were not marked. As a result, channel No. 1 adults of this brood year were indistinguishable from unmarked river and channel No. 2 returns and were treated in the analysis as of either river or channel No. 2 origin. The effect of this approach is minimal since contribution from channel No. 1 fry was only 1.7% of the system production.

Appendix 37 - Assignment of commercial catches of chum adults to brood year and source of origin, and commercial catch estimates.

Data and calculations showing the assignment of chum commercial catches to brood year and source of origin are available in the DFO, Big Qualicum River file No. 5903-85-Q5-b and e.

Commercial processing plants have been monitored since the first mark returns in 1967. The DFO personnel recorded sample sizes, number of marks recovered, and the total number of chum caught by fishermen in the various marine management zones (Fig. 34). Scales for age analysis were taken from marked fish.

Early estimates of the Big Qualicum River chum catch were based on expansion of the marks recovered in the catch using the mark rate observed among dead-pitched spawners and assuming that marks were uniformly distributed throughout the population. The exploitation rates obtained for the 1965 and 1966 broods, for example, were typical representing close to 40% and 50% of the returns (Append. Table 37-1). However, with the introduction of daily live sampling for marked returns at hub 290 in 1970, a more dynamic examination of the chum population revealed that the mark rate was not homogeneous over time. Rather, significant changes occurred during the upstream migration and presumably, also during the commercial fisheries. Therefore the catch estimates based on the mean annual mark rate were dubious.

During 1972 to 1973, chum adults were captured in standard commercial fishing locations (Fig. 34), then tagged and released by DFO personnel. Of the tagged fish, 2500 were recovered in the Big Qualicum River and the time required to migrate from each fishing area to the river was computed (Append. Table 37-2). The data indicate that, as the season progressed, migration time decreased. The appropriate ratio of marked to unmarked fish for any time period was known for the 1970 to 1974 returns from the live sample data. Therefore, after extrapolation of the marks found in the cannery samples to the total fishery catch, it required only the application of marked:unmarked ratio at the fence for the appropriate time period (Append. Table 37-2) to calculate the total number of captured Big Qualicum River chum salmon. Only AdLV and AdRV mark recoveries were used in total catch estimates. Live sampling was not conducted in 1968, 1969 and 1975; therefore, dead pitch sample data summarized over weekly intervals were utilized. In calculating the applicable mark rate for these three catch years, 14 days were added to the migration period to compensate for the time between passing the fence and carcass sampling. Catch of the Big Qualicum River chum was estimated for each fishery in which double clips were recovered.

Age composition for the annual commercial catch of Big Qualicum River chum during 1968 to 1975 was calculated by weighting the number of marks at each age in each fishery with the catch to sample ratio, summing over the season, then normalizing to an equal fry mark rate. With this information it was possible to assign the catch to brood years.

In order to allot portions of each catch to either a river or spawning channel origin, a procedure similar to that employed for the escaping AdLV -and AdRV-marked chum was used. A ratio of river to channel catch was calculated for each age class of each brood. As was the case for the escaping population, it was necessary to remove any contribution by freshwater-reared chum to the catch before these ratios could be applied. This component was handled in a manner comparable to escaping AdAn marks, again assuming a 20% mark mortality.

Appendix Table 37-1. Preliminary catch estimates for Big Qualicum River chum using Peterson method, 1965 and 1966 broods.

Brood year	Source	Catch at age 3	4	5	Total catch	Total escapement	Exploitation (%)
1965	River	375	2,842	246	3,463		
	Channel	8,777	39,800	1,726	50,303		
	System	9,652	42,642	1,972	53,766	89,738	37.5
1966	River	1,887	5,247	111	7,245		
	Channel	46,312	131,547	387	178,246		
	System	48,199	136,794	498	185,491	182,030	50.5

Appendix Table 37-2. Time in days for Big Qualicum River chum to migrate from sites of commercial fishing to hub 290 at Big Qualicum River.

Week ending	Area 12[a] Upper Johnstone St.	Area 13 Lower Johnstone St.	Area 14 Qualicum-Baynes Sound
October 7	41.4	32.3	-
October 14	40.9	31.8	-
October 21	40.8	31.7	24.2
October 28	33.0	23.9	21.8
November 4	34.4	25.3	21.7
November 11	33.7	24.6	16.8
November 18	30.2	21.1	10.1
November 25	-	-	8.9
December 2	-	-	8.2
Seasonal Mean ±1 S.E.	35.7±0.45	26.6±0.5	9.8±0.2

[a] Fish migrating through Statistical Area 20 (Juan de Fuca Area) in 1972 and 1973 were assumed to reach the fence in the same period of time as required from Statistical Area 12.

Only channel fry were marked in the 1971 and 1972 broods. Assignment of catch from these broods was handled as for the escapement; that is, by utilizing survivals of the river versus channel fish in earlier broods. Ratios based on live sample data were chosen wherever possible.

Prior to 1966, only river chum were present in the catch but returns of the 1963 and 1964 broods in 1966 through 1969 could not be directly allotted to the source of origin since differential marking program had not been initiated. Catch of these two broods was handled the same way as that of the 1971 and 1972 broods; that is, by applying the relative survival of 1965 and 1966 brood river versus channel No. 1 fish.

Commercial catch of channel No. 1, 1967 brood chum was handled in a manner similar to escapement.

Commercial catch of Big Qualicum River 1964 brood chum was approximated by applying equation (E1) (Append. 36) to Ad mark recoveries in 1967, 1968 and 1969. Mark mortality was assumed to be zero, while natural occurrence of missing adipose fins was set at 0.05% (DFO, Big Qualicum River file No. 5903-85-Q5-c). Dead pitch age data were used to assign the catch to brood year.

No mark information was available for broods predating 1964, but total catches by date and area were known (B.C. Catch Statistics, Dept. Fish., Canada, Pacific Area, 1962-1966). To estimate the commercial catch of Big Qualicum River chum broods prior to 1964, all the AdLV and AdRV mark return data were examined and the mean proportions of Big Qualicum River fish in the catch in different areas at different times were calculated. These fractions were then applied to the total catch data in 1962 through 1966 to yield an estimate of Big Qualicum River stock exploitation. Only total catches greater than 500 fish were included in these calculations. For fishery dates outside the period when estimates of the proportions of Big Qualicum River to total catch were known, the nearest figure was used. For example, Big Qualicum River fish were assumed to comprise 0.66% of the September week 5 catches in 1964 to 1966 although this figure represented October week 2. Total catch estimates were assigned to age classes using dead pitch age composition data. (see DFO, Big Qualicum River file No. 5903-85-Q5-e for details).

Although the methodology used to estimate catches of the 1959 to 1963 broods is approximate it is felt that any error involved is of little consequence since relatively few fish were involved. Furthermore, in most cases, the Big Qualicum River contribution to the commercial catch in a specific area and time period was quite reproducible from year to year indicating that the relative timing of Big Qualicum River stocks compared to other stocks is constant. This lends some support to the analytical approach.

Appendix 38. Sex composition of coho adults in Big Qualicum River, 1959-1972 (n gives sample size).

Year	Sample type	n	Sex composition: Total escapement (% females)	Sex composition: Adults (% females)
1959	dead	76	43.8	52.6
1960	-	-	-	-
1961	live	424	43.0	57.8
1962	live	179	50.8	55.3
1963	dead	88	-	72.7
1964	dead	99	49.1	53.5
1965	dead	168	43.6	53.6
1966	dead	47	44.5	51.1
1967	dead	83	35.7	44.6
1968	dead	97	45.7	50.5
1969	live	539	54.1	67.9
1970	dead	31	28.9	58.1
1971	-	-	-	-
1972	live	775	25.5	50.7
Mean ±1 S.D.	-	-	42.2±8.9	55.7±7.8

Appendix 39. Mean (±1 S.D.) length of coho adults by age in Big Qualicum River, 1959-1972 (n gives sample size).

Year	Age 2_1: n	Age 2_1: Length (mm)	Age 3_1: n	Age 3_1: Length (mm)	All ages: n	All ages: Length (mm)
1959	11	298±30	55	512±30	128	461±104
1960	-	-	-	-	50	518±72
1961	65	284±40	218	524±36	514	481±105
1962	12	323±17	327	572±53	396	557±76
1963	2	428±137	88	566±43	117	550±53
1964	-	-	85	560±60	99	560±59
1965	1	337	160	574±41	169	572±46
1966	1	330	16	528±53	24	519±64
1967	-	-	3	476±51	83	612±137
1968	-	-	21	493±53	149	492±49
1969	5	427±114	110	521±30	624	509±59
1970	5	341±122	363	536±52	705	529±64
1971	5	355±96	840	499±53	1,115	497±55
1972	16	293±14	227	508±57	379	485±67
Mean ±1 S.D.	-	342±51	-	527±32	-	525±43

Appendix 40. Mean (±1 S.D.) length of coho males by age in Big Qualicum River, 1959-1972 (n gives sample size).

Year	Age 2_1		Age 3_1		All ages	
	n	Length (mm)	n	Length (mm)	n	Length (mm)
1959	11	298±50	24	528±59	66	429±131
1960	-	-	-	-	16	500±95
1961	64	282±35	104	538±56	269	454±130
1962	12	323±17	164	554±57	208	529±88
1963	2	428±137	39	556±46	54	543±60
1964	-	-	37	535±58	46	537±59
1965	1	337	73	564±39	79	559±49
1966	1	330	-	-	1	330[a]
1967	-	-	2	495±56	46	580±99
1968	-	-	10	484±68	64	486±59
1969	4	421±131	36	506+64	217	486±75
1970	4	286±3	90	550±42	182	519±81
1971	5	355±96	218	491±56	303	489±62
1972	16	293±14	88	488±60	162	463±80
Mean ±1 S.D.	-	335±53	-	524±30	-	506±44

[a] Excluded from grand mean.

Appendix 41. Mean (±1 S.D.) length of coho females by age in Big Qualicum River, 1959-1972 (n gives sample size).

	Age 3_1		All ages	
Year	n	Length (mm)	n	Length (mm)
1959	31	500±38	62	495±44
1960	-	-	34	527±59
1961	114	511±52	245	512±52
1962	163	589±42	188	587±41
1963	49	574±39	63	570±42
1964	48	579±55	53	580±53
1965	87	583±41	90	583±40
1966	16	520±53	23	527±50
1967	1	440	37	651±166
1968	10	503±36	84	497±40
1969	66	531±36	386	523±43
1970	273	532±54	523	532±56
1971	622	502±52	812	500±52
1972	139	508±53	217	502±50
Mean ±1 S.D.	-	529±43	-	542±46

Appendix 42. Egg retention of coho in Big Qualicum River, 1959-1968 (n gives sample size).

Year	n	Mean length of females (mm)	Mean fecundity (eggs/female)	Estimated egg content	No. eggs retained	Egg retention (%)
1959	15	503	1,819	27,285	6,930	25.4
1960	33	524	1,980	65,340	31,045	47.5
1962	89	588	2,471	219,919	32,228	14.7
1963	63	570	2,964	186,732	15,931	8.5
1964	52	581	3,070	159,640	23,311	14.6
1965	90	583	3,089	278,010	23,285	8.4
1966	23	527	2,552	58,969	14,220	24.1
1967	11	446	1,775	19,525	5,509	28.2
1968	25	503	2,322	58,050	15,143	26.1
Mean ±1 S.D.	-	-	-	-	-	22.0±12.2

Appendix 43. Linear regression analysis of coho fecundity (y) on length (x) where y = bx + a, Big Qualicum River, 1959-1962, 1969-1972 (n gives sample size).

Year	n	Mean length of females[a] (mm)	Mean fecundity (eggs/female)	Intercept (a)	Slope (b)	Correlation coefficient[b]
1959-1962	50	566	2,306	-2,039	7.67	0.57**
1969	50	535	3,111	-1,796	9.16	0.62**
1970	70	562	2,863	-1,508	7.78	0.50**
1971	77	523	2,703	-3,708	12.26	0.76**
1972	77	516	2,356	-2,851	10.08	0.70**
Overall	324	538	2,657	-2,502	9.59	0.64**

[a] Post-orbital-hypural.
[b] ** $p < 0.01$.

Appendix 44. Mean (±1 S.D.) length, weight and condition coefficient of coho smolts in Big Qualicum River, 1958-1972 broods (n gives sample size).

Principal brood year	Length n	Length (mm)	Weight n	Weight (g)	Condition coefficient (mg/mm^3) X100
1958	345	98.6±12.0	0	-	-
1959	338	94.6±13.1	148	9.83±2.80	1.115
1960	221	90.6±12.3	117	8.65±2.58	1.146
1961	341	96.5±8.3	156	9.29±2.29	1.066
1962	306	92.7±8.9	0	-	-
1963	119	109.3±11.0	119	14.44±4.53	1.101
1964	250	104.7±12.3	18	15.18±3.84	1.116
1965	228	96.4±10.7	0	-	-
1966	86	101.1±9.7	0	-	-
1967	89	108.4±11.6	89	14.26±5.06	1.119
1968	1,153	96.7±10.9	1,153	9.93±3.21	1.097
1969	659	98.7±10.4	659	11.03±3.36	1.129
1970	793	98.0±11.0	793	11.04±3.94	1.167
1971	944	90.0±17.0	944	8.01±3.33	1.099
1972	396	101.5±12.0	396	11.37±3.40	1.087

Appendix 45. Coho fry downstream totals from different areas of the Big Qualicum River system, 1959-1972 broods.[a]

Brood year	Hub 290	Hub 280	Channel No. 2 fence	Main river above hub 290 (inc. Hunt's Creek)	Hunt's Creek	Main river above hub 290 (exc. Hunt's Creek)	Hunt's Cr. flood channel	Hunt's Creek total	Channel No. 2 fyke net	Total Channel No. 2	Channel No. 1	System total
1959	159,000	0	0	159,000	-	-	-	-	0	0	0	159,000
1960	18,200	0	0	18,200	-	-	-	-	0	0	0	18,200
1961	71,900	0	0	71,900	-	-	-	-	0	0	0	71,900
1962	32,500	0	0	32,500	73,300	0	-	73,300	0	0	0	32,500[b]
1963	367,000	0	0	367,000	72,400	295,000	1,060	73,500	0	0	16,500	385,000
1964	585,000	0	0	585,000	81,200	503,000	0	81,200	0	0	13,500	598,000
1965	608,000	0	0	608,000	31,700	576,000	0	31,700	0	0	43,700	652,000
1966	334,000	0	0	334,000	68,600	266,000	0	68,600	0	0	44,200	379,000
1967	143,000	5,550	20,500	128,000	1,270	127,000	1	1,270	479	21,000	1,200	150,000
1968	149,000	9,880	4,950	154,000	32,700	122,000	662	33,300	585	5,540	0	161,000
1969	58,800	4,430	29,600	33,600	3,720	29,900	26	3,750	3,690	33,300	0	66,900
1970	80,800	4,720	21,500	63,900	0	63,900	89	89	1,710	23,300	0	87,300
1971	1,620,000	762	12,000	1,610,000	0	1,610,000	77,300	77,300	3,290	15,300	0	1,700,000
1972	13,600	0	10,100	3,450	0	3,450	12	12	1,970	12,100	0	15,500

[a] Juveniles passing through fences at Hunt's Creek and channel No. 1 were allowed to continue downstream to the main fence at hub 290. Catches at hub 280 and the channel No. 2 fyke net were released below hub 290. Migrants from the flood channel and channel No. 1 were not included in the catch at hub 290.

[b] Since the number of fry migrating from the river is less than that from Hunt's Creek, most of the Hunt's Creek fish must have remained to rear in the river or died; or enumeration of creek or river migrants must have been incorrect.

Appendix 46. Coho smolt downstream totals from different areas of the Big Qualicum River system, 1958-1972 broods.

Brood year	Hub 290	Hub 280	Channel No. 2 fence	Main river above hub 290 (inc. Hunt's Creek)	Hunt's Creek	Main river above hub 290 (exc. Hunt's Creek)	Hunt's Cr. flood channel	Total Hunt's Creek	Channel No. 1	Channel No. 2	Main river below hub 290[a]	System total wild fish	Hatchery incubated and reared (released below hub 290)	Total downstream (wild & hatchery)
1958	18,000	0	0	18,000	-	-	-	-	0	0	1,110	19,100	0	19,100
1959	29,300	0	0	29,300	-	-	-	-	0	0	1,820	31,100	0	31,100
1960	24,600	0	0	24,600	-	-	-	-	0	0	1,520	26,100	0	26,100
1961	29,500	0	0	29,500	4,970	24,500	2,290	7,260	0	0	1,950	33,700	0	33,700
1962	29,900	0	0	29,900	4,000	25,900	1,010	5,010	933	0	2,060	33,900	0	33,900
1963	33,000	0	0	33,000	4,250	28,800	127	4,380	340	0	2,330	35,800	0	35,800
1964	25,800	0	0	25,800	2,750	23,000	3,180	5,930	135	0	1,820	30,900	0	30,900
1965	27,000	0	0	27,000	4,550	22,400	442	4,990	161	0	1,770	29,300	0	29,300
1966	15,900	287	121	16,100	3,460	12,600	2,230	5,690	103	121	1,000	19,600	0	19,600
1967	34,400	1,010	36	35,300	508	34,800	92	600	0	36	2,770	38,200	0	38,200
1968	54,400	1,730	833	55,300	2,930	52,400	693	3,620	0	834	4,160	61,000	69,100	130,000
1969	13,200	110	66	13,200	0	13,200	3,800	3,800[c]	0	66	1,050	18,100	88,200	106,000
1970	28,600	155	361	28,400	0	28,400	8,070	8,070[c]	0	363	2,100	38,900	210,000	249,000
1971	51,500	8,160	1,210	58,500	0	58,500	7,870	7,870[c]	0	1,210	4,650	72,200	183,000	255,000
1972	29,500[b]	649	-	30,100	0	30,100	4,100	4,100[c]	0	-	-	34,200	182,000	217,000
											Mean = 2,151			

[a] It is assumed that the river per unit length below hub 290 will support as many juveniles during rearing as above hub 290. The fingerling production below the fence is calculated as: $F_1 \times 793/9934$ where F_1 is the number reared in the river above the fence and the ratio is the length of river (m) below to above the fence.

[b] Hub 287.

[c] At least 1,600 smolts originating from the transplant of fry into Hunt's Creek are included in these data.

Appendix 47. Sex composition of coho adults in Hunt's Creek, 1962-1966 (n gives sample size).

Year	Sample type	n	Sex composition of adults (% females)
1962	dead	382	55.0
1963	dead	99	52.5
1964	dead	200	50.5
1965	live	273	37.7
1966	dead	39	46.2
Mean ±1 S.D.	-	-	48.4±6.8

Appendix 48. Mean (±1 S.D.) length of coho adults by age and sex in Hunt's Creek, 1959-1968 (n gives sample size).

		Age 2		Age 3		All ages	
Year	Sex	n	Length (mm)	n	Length (mm)	n	Length (mm)
1959	Both	-	-	7	516±56	31	499±77
1962		2	357±17	144	594±46	220	589±54
1963		1	487	71	559±43	99	554±49
1964		-	-	170	554±47	200	554±46
1966		-	-	32	520±42	39	518±40
1968		-	-	2	475±64	16	496±35
Mean ±1 S.D.		-	422±92	-	536±41	-	535±37
1959	Male	-	-	5	525±63	21	500±94
1962		2	357±17	63	576±53	95	566±66
1963		1	487	33	548+39	48	537±49
1964		-	-	86	538±48	99	539±46
1966		-	-	19	538±35	21	535±34
1968		-	-	2	475±64	13	496±36
Mean ±1 S.D.		-	422±92	-	533±33	-	529±26
1959	Female	-	-	2	492±34	10	496±17
1962		-	-	81	609±33	125	606±33
1963		-	-	38	569±45	51	570±44
1964		-	-	84	571±40	101	570±40
1966		-	-	13	495±40	18	499±38
1968		-	-	-	-	3	497±36
Mean ±1 S.D.		-	-	-	547±52	-	540±42

Appendix 49. Egg retention of coho in Hunt's Creek, 1962-1964, 1966 (n gives sample size).

Year	n	Mean length of females (mm)	Mean fecundity (eggs/female)	Projected egg content	No. eggs retained	Egg retention (%)
1962	121	606	2,609	315,691	6,325	2.00
1963	51	570	2,964	151,164	2,624	1.74
1964	100	570	2,964	296,430	23,246	7.84
1966	18	499	2,283	41,101	1,028	2.50
Mean ±1 S.D.	-	-	-	-	-	3.52±2.90

Appendix 50. Mean (±1 S.D.) length, weight and condition coefficient of coho smolts in Hunt's Creek, 1961-1972 broods (n gives sample size).

Principal brood year	Length		Weight		Condition coefficient (mg/mm^3) X100
	n	(mm)	n	(g)	
1961	387	82.9±10.7	387	6.59±2.60	1.135
1962	317	81.0±11.6	61	4.32±2.20	1.207
1963	90	83.6±8.0	90	6.80±1.81	1.151
1964	265	80.6±10.8	43	6.16±2.79	1.176
1965	294	77.7±10.3	0	-	-
1966	175	90.8±7.6	0	-	-
1969	336	93.1±7.2	336	8.60±2.07	1.065
1970	217	89.7±8.4	217	7.66±2.14	1.060
1971	1,105	89.5±9.5	1,105	7.30±2.00	1.019
1972	928	93.0±8.8	928	8.10±2.40	1.007

Appendix 51. Transplants of hatchery incubated coho fry into Hunt's Creek, 1969-1971 broods.

Brood year	Transplant date	Number transplanted
1969	April 1970	30,833
1970	May 24-25, 1971	60,435
1971	March 24 - May 23, 1972	130,677

Appendix 52. Sex composition of chinook adults in Big Qualicum River, 1959-1972 (n gives sample size).

Year[a]	n	Total escapement (% females)	River above hub 290 (% females)	Escapement excluding jacks (% females)
1959	70	51.7	51.7	-
1960	97	52.6	52.6	-
1961	136	36.0	36.0	-
1962	360	60.8	60.8	-
1963	135	57.8	57.8	-
1964	80	36.4	38.0	55.3
1965	140	53.5	53.5	60.0
1966	204	52.1	52.1	70.1
1967	213	44.8	42.6	50.7
1968	280	26.9	17.4	65.3
1969	364	25.7	27.9	45.4
1970	123	34.9	24.3	45.5
1971	453	48.3	43.4	58.7
1972	682	52.2	34.3	42.9
Mean ±1 S.D.	-	45.3±11.3	42.3±13.2	54.9±9.5

[a] Dead pitch samples (1959, 1960, 1962); live samples (1961, 1963, 1964, 1965); dead pitch samples and holding pond samples (1966-1970); holding pond samples (1971); and live samples and holding pond samples (1972).

Appendix 53. Age composition of chinook adults in Big Qualicum River, 1959–1972.

Year	Age 2 (%)			Age 3 (%)			Age 4 (%)			Age 5 (%)		
	Male	Female	Overall	Male	Female	Overall	Male	Female	Overall	Male	Female	Overall
1959	19.5	0.0	19.5	19.4	5.6	25.0	19.4	27.8	47.2	0.0	8.3	8.3
1960	6.8	0.0	6.8	5.4	2.7	8.1	35.1	48.7	83.8	0.0	1.3	1.3
1961	29.6	0.0	29.6	33.3	7.4	40.7	5.6	23.2	28.8	0.0	0.9	0.9
1962	9.9	0.0	9.9	14.9	13.2	28.1	10.7	49.6	60.3	0.0	1.7	1.7
1963	3.2	0.0	3.2	7.0	2.5	9.5	24.6	59.5	84.1	0.0	3.2	3.2
1964	28.0	0.0	28.0	36.0	12.0	48.0	8.0	16.0	24.0	0.0	0.0	0.0
1965	9.4	0.0	9.4	27.3	13.6	40.9	15.7	33.6	49.3	0.0	0.4	0.4
1966	17.9	0.0	17.9	14.3	5.1	19.4	9.2	50.5	59.7	0.5	2.5	3.0
1967	12.7	0.0	12.7	33.0	16.5	49.5	9.2	26.2	35.4	1.5	0.9	2.4
1968	57.6	0.0	57.6	6.0	2.5	8.5	7.7	26.2	33.9	0.0	0.0	0.0
1969	39.1	0.0	39.1	31.6	14.2	45.8	5.6	8.4	14.0	0.1	1.0	1.1
1970	36.0	0.0	36.0	8.1	5.9	14.0	9.0	40.1	49.1	0.0	0.9	0.9
1971	18.5	0.0	18.5	23.2	11.8	35.0	8.1	35.4	43.5	0.3	2.7	3.0
1972	8.6	0.0	8.6	17.7	3.4	21.1	21.3	46.1	67.4	0.0	2.9	2.9
Mean ±1 S.D.	21.2±15.3	0.0	21.2±15.3	19.8±11.0	8.3±5.0	28.1±15.2	13.5±8.7	35.1±14.7	48.6±21.0	0.2±0.4	1.9±2.1	2.1±2.1

Appendix 54. Mean (±1 S.D.) length of chinook adults by age in Big Qualicum River, 1959-1972 (n gives sample size).

Year	Age 2		Age 3		Age 4		Age 5		All ages	
	n	Length (mm)	n	Length (mm)	n	Length (mm)	n	Length (mm)	n	Length (mm)
1959	7	538±87	9	638±139	17	839±96	3	862±58	123	750±159
1960	5	516±26	6	738±155	62	862±53	1	845	100	824±115
1961	28	503±61	44	724±73	31	850±56	1	805	136	698±151
1962	12	550±59	34	741±74	73	859±51	2	895±0	161	802±107
1963	1	500	6	793±145	53	849±61	2	917±8	80	831±95
1964	7	515±19	12	716±54	6	843±73	0	-	33	693±137
1965	27	530±91	117	744±73	141	828±62	1	860	374	765±110
1966	35	459±34	38	696±68	117	776±44	6	833±32	250	702±132
1967	11	435±38	102	658±58	73	761±54	5	807±70	227	687±99
1968	35	464±26	37	674±84	149	754±42	0	-	331	695±114
1969	67	432±64	296	658±70	90	753±67	7	797±52	616	645±125
1970	16	407±45	73	682±79	256	765±45	5	797±44	445	729±95
1971	1	380	116	644±43	144	745±47	10	789±42	282	702±72
1972	0	-	94	646±46	301	746±45	13	768±60	479	726±61
Mean ±1 S.D.	-	479±54	-	697±47	-	802±48	-	831±46	-	732±56

Appendix 55. Mean (±1 S.D.) length of chinook males by age in Big Qualicum River, 1959-1972, (n gives sample size).

Year	Age 2		Age 3		Age 4		Age 5		All ages	
	n	Length (mm)	n	Length (mm)	n	Length (mm)	n	Length (mm)	n	Length (mm)
1959	7	538±87	7	690±107	7	821±137	0	-	62	686±164
1960	5	516±26	4	673±132	26	880±54	0	-	46	796±151
1961	28	503±61	36	717±74	6	865±39	0	-	87	640±141
1962	12	550±59	18	739±64	13	870±57	0	-	55	745±134
1963	1	500	4	840±107	12	867±80	0	-	20	814±138
1964	7	515±19	9	712±57	2	827±97	0	-	22	645±125
1965	27	530±91	78	735±79	45	833±74	0	-	187	726±131
1966	35	459±34	28	677±64	18	787±47	1	845	107	607±149
1967	11	435±38	68	658±66	19	748±55	3	767±59	119	648±105
1968	35	464±26	26	651±82	34	752±56	0	-	148	623±133
1969	67	432±64	204	649±79	36	740±96	1	865	402	607±133
1970	16	407±45	42	673±83	47	767±41	0	-	143	675±132
1971	1	380	77	642±46	27	730±56	1	800	109	664±70
1972	0	-	79	643±41	95	739±55	0	-	190	697±69
Mean ±1 S.D.	-	479±54	-	693±54	-	802±56	-	819±44	-	684±66

Appendix 56. Mean (±1 S.D.) length of chinook females by age in Big Qualicum River, 1959-1972 (n gives sample size).

Year	Age 3		Age 4		Age 5		All ages	
	n	Length (mm)	n	Length (mm)	n	Length (mm)	n	Length (mm)
1959	2	455±21	10	851±59	3	862±58	61	815±126
1960	2	868±131	36	849±50	1	845	53	847±65
1961	8	758±57	25	846±60	1	805	49	801±108
1962	16	744±87	60	856±50	2	895±0	106	832±73
1963	1	845	34	836±53	2	917±8	47	845±52
1964	3	728±53	4	852±74	0	-	11	788±111
1965	39	763±53	96	826±55	1	860	187	803±65
1966	10	747±57	99	774±44	5	830±35	143	773±48
1967	34	660±40	54	766±53	2	868±18	108	730±71
1968	10	717±50	115	754±38	0	-	182	752±40
1969	91	678±36	54	761±35	6	786±46	213	718±58
1970	31	693±74	209	764±46	5	797±44	302	755±55
1971	39	648±38	117	748±44	9	788±45	173	726±62
1972	15	666±62	206	750±38	13	768±60	289	745±46
Mean ±1 S.D.	-	712±98	-	802±45	-	835±47	-	781±44

Appendix 57. Egg retention of chinook in Big Qualicum River, 1960-1972 (n gives sample size).

Year	n	Mean length of females (mm)	Mean fecundity (eggs/female)	Projected egg content	No. eggs retained	Egg retention (%)
1960	51	847	5,646	287,946	37,344	13.0
1962	93	826	5,478	509,454	68,218	13.4
1963	56	848	5,978	334,768	32,681	9.8
1965	84	765	5,225	438,900	11,210	2.55
1966	143	773	5,298	757,614	15,122	2.0
1969	164	718	5,089	834,596	142,523	17.1
1970	60	750	4,642	278,520	84,254	30.3
1972	38	750	5,235	198,930	342	0.17
Mean ±1 S.D.	-	-	-	-	-	11.0±9.9

Appendix 58. Linear regression analysis of chinook fecundity (y) on length (x) where y=bx+a, Big Qualicum River, 1960, 62, 68-72 (n gives sample size).

Year	n	Mean length of females (mm)	Mean fecundity (eggs/female)	Intercept (a)	Slope (b)	Correlation coefficient[b]
1960, 62	12	787	5,173	-1,130	8.00	0.41 n.s.
1968	31	741	4,834	1,625	4.33	0.34 n.s.
1969	28	716	5,080	2,087	4.18	0.22 n.s.
1970	155	753	4,663	-1,141	7.71	0.38 **
1971	92	740	5,487	316	7.00	0.36 **
1972	185	747	5,189	-4,395	12.84	0.12 n.s.
Overall	503	746	5,053	-1,713	9.07	0.27 **

[a] Post-orbital-hypural.

[b] n.s. $p > 0.05$.

** $p < 0.01$.

Appendix 59. Mean (±1 S.D.) length, weight and condition coefficient of chinook fry and fingerlings in Big Qualicum River, 1959-1972 broods (n gives sample size).

	Fry				Fingerlings			
Brood year	n	Length (mm)	Weight (mg)	Condition coefficient ($mg/mm^3 x100$)	n	Length (mm)	Weight (g)	Condition coefficient ($mg/mm^3 x100$)
1959	-	-	-	-	571	93.0±10.2	-	-
1960	75	45.9±3.1	-	-	151	67.9±6.8	-	-
1961	327	44.3±2.5	-	-	456	64.4±6.0	2.81	1.056
1962	-	-	-	-	220	69.6±6.4	3.77±0.96	1.076
1963	-	-	-	-	130	76.3±7.2	4.83±1.32	1.060
1964	361	43.3±2.8	650±210	0.773	337	73.6±7.1	4.10±1.18	1.027
1965	432	42.4±1.7	570±80	0.746	476	67.8±5.7	3.40±0.89	0.959
1966	277	44.2±2.2	670±140	0.761	432	71.5±6.6	3.86±1.08	1.022
1967	179	41.5±2.2	510±100	0.710	243	74.5±5.7	4.35±0.97	1.036
1968	411	42.5±2.5	600±140	0.758	742	75.0±8.4	4.59±1.52	1.055
1969	200	41.7±3.1	570±180	0.770	1,129	72.5±5.9	4.18±1.07	1.002
1970	781	45.8±3.2	690±210	0.802	978	70.6±6.2	3.76±0.99	1.034
1971	941	44.0±3.2	680±210	0.736	781	68.7±6.7	3.44±0.95	1.113
1972	664	42.5±2.7	620±260	0.771	915	72.7±9.5	4.16±1.62	1.068

Appendix 60. Chinook migrant fry production and downstream totals from different areas of the Big Qualicum River system, 1959–1972 broods.

Brood year	Hub 290	Hub 280	Channel No. 2 fence	Main river above hub 290	Channel No. 1	Channel No. 2 total	Total migrant fry	Net downstream[a]
1959	107,000	0	0	107,000	0	0	107,000	107,000
1960	3,010	0	0	3,010	0	0	3,010	3,010
1961	31,500	0	0	31,500	0	0	31,500	31,500
1962	44,100	0	0	44,100	0	0	44,100	44,100
1963	296,000	0	0	296,000	766	0	297,000	297,000
1964	47,700	0	0	47,700	3,040	0	50,700	50,700
1965	202,000	0	0	202,000	0	0	202,000	202,000
1966	152,000	0	0	152,000	0	0	152,000	152,000
1967	19,000	144	990	18,200	0	1,030	19,200	12,100
1968	104,000	85,800	479	189,000	0	479	190,000	130,000
1969	68,500	23,200	247	91,300	0	247	91,500	71,600
1970	36,200	7,190	0	43,400	0	0	43,400	43,400
1971	114,000	0	63	114,000	0	63	114,000	114,000
1972	40,400	0	0	40,400	0	0	40,400	40,400
Mean ±1 S.D.	–	–	–	–	–	–	99,000±84,700	92,800±81,900

[a] Difference between production and downstream numbers represents fry trapped at hub 280 or hub 290 and held for freshwater rearing.

Appendix 61. Chinook fingerling downstream totals from different areas of the Big Qualicum River system, 1959-1972 broods.

Brood year	Hub 290	Hub 280	Channel No. 2 fence	Main river above hub 290	Main river below hub 290[a]	Spawning channels[b]	Total wild downstream	River fry reared in hatchery and released as fingerlings into Big Qualicum River	Hatchery incubated, reared and released into Big Qualicum River	Total hatchery reared downstream	Total downstream
1959	49,400	0	0	49,400	3,920	0	53,300	0	0	0	53,300
1960	4,600	0	0	4,600	365	0	4,970	0	0	0	4,970
1961	66,300	0	0	63,300	5,030	0	68,300	0	0	0	68,300
1962	105,000	0	0	105,000	8,340	0	113,000	0	0	0	113,000
1963	38,100	0	0	38,100	3,030	356	41,500	0	0	0	41,500
1964	69,900	0	0	69,900	5,550	5,710	81,200	0	0	0	81,200
1965	48,000	0	0	48,000	3,810	0	51,800	0	0	0	51,800
1966	40,500	0	0	40,500	3,220	0	43,700	0	0	0	43,700
1967	19,700	539	646	19,600	1,560	646	21,800	3,980	247,000	251,000	272,800
1968	123,000	8,350	0	131,000	10,400	0	142,000	50,500	256,000	306,500	448,500
1969	59,800	1,270	44	61,000	4,850	44	65,900	8,810	0	8,810	74,700
1970	43,100	2,210	0	45,300	3,600	0	48,900	0	88,200	88,200	137,100
1971	103,000	16,600	14	120,000	9,530	14	129,000	0	166,000	166,000	295,000
1972	21,300	14,000	0	35,300	2,800	0	38,100	0	517,000	517,000	555,100
Mean ±1 S.D.	-	-	-	59,400±36,600	4,715±2,906	-	64,500±39,600	-	-	-	-

[a] It is assumed that all chinook spawning occurred above hub 290 but that some fry passing through the fence reared in the lower river, and that the lower river (793m) supported as many fingerlings per unit length as the upper river (9,984m).

[b] Channel No. 1: 1963-1964 broods;
Channel No. 2: 1967, 1969, 1971 broods.

Appendix 62. Division of Big Qualicum River chinook escapements by age, 1959-1977.

Escapement year	Total escapement[a]	Escapement at age [b]							
		2		3		4		5	
		%	No.	%	No.	%	No.	%	No.
1959	2,411	19.5	470	25.0	603	47.2	1,138	8.3	200
1960	1,570	6.8	107	8.1	127	83.8	1,316	1.3	20
1961	1,111	29.6	329	40.7	452	28.8	320	0.9	10
1962	797	9.9	79	28.1	224	60.3	480	1.7	14
1963	636	3.2	20	9.5	61	84.1	535	3.2	20
1964	813	18.5	150	54.3	441	27.2	221	0.0	0
1965	1,265	10.8	137	40.3	510	48.5	614	0.4	5
1966	1,180	25.4	300	17.6	208	54.2	640	2.7	32
1967	887	12.7	113	49.5	439	35.4	314	2.4	21
1968	1,342	57.6	773	8.5	114	33.9	455	0.0	0
1969	2,403	39.1	939	45.8	1,101	14.0	337	1.1	26
1970	1,670	36.0	601	14.0	234	49.1	820	0.9	15
1971	1,434	19.5	280	34.6	496	43.0	616	3.0	42
1972	934	8.5	79	21.1	197	67.5	630	2.9	27
1973	1,284	49.9	641	2.1	27	44.1	566	3.9	50
1974	765	27.6	211	49.7	380	19.5	149	3.3	25
1975	1,725	23.8	410	14.4	249	60.8	1,049	1.0	17
1976	1,629	39.2	638	25.4	413	32.4	527	3.0	48
1977	3,186	22.7	724	31.5	1,003	42.2	1,345	3.6	114

[a] Escapements include wild and hatchery reared fish; 6-year olds, if present, are only included in totals.

[b] Division of escapement during 1959-1963 is by the main river age composition sample data. In later years, the age 2 fish were represented by the total number of jacks and the large fish were assigned to age by their relative abundance in the main river.

Appendix 63. Data used in regression analyses of Big Qualicum River chum salmon egg retention, egg survival and fry survival, 1959-1972 broods.

	Brood year													
	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Egg retention														
Min. daily discharge during escapement (m^3/sec)[a]	2.8	4.4	3.1	1.7	8.3	4.2	5.3	6.3	4.2	4.9	4.7	1.9	6.4	3.9
Max. daily discharge during escapement (m^3/sec)[a]	38.5	23.6	10.2	29.7	19.3	8.2	18.8	24.1	15.5	10.3	11.6	10.3	9.2	9.4
Density of female spawners (No./m^2)	1.21	0.64	0.16	0.50	0.43	0.38	0.10	0.36	0.10	0.47	0.26	0.36	0.29	0.16
Egg survival during incubation														
Max. daily discharge during incubation (m^3/sec)[b]	38.5	90.6	35.7	42.2	22.8	19.3	20.8	24.1	21.7	11.1	11.6	12.5	13.2	25.0
Min. temperature during December (°C)	6.1	7.5	4.2	5.0	5.6	1.7	5.0	5.0	3.9	1.9	4.4	2.8	2.2	3.3
Change in temperature from March to May (°C)	4.8	5.1	6.2	4.9	5.2	6.6	7.4	6.0	5.5	4.9	6.2	4.1	6.3	5.9
Mean temperature during incubation (°C)[b]	6.7	7.7	5.8	6.6	6.8	5.4	5.8	5.3	5.6	4.6	5.7	5.3	4.7	4.8
Accumulated thermal units during incubation (°C-days)	1,072	1,132	835	1,010	1,047	869	876	816	874	800	832	928	761	710
Fry survival														
Mean salinity of surface water at Chrome Island during April through August of the downstream year (ppt)	-	26.7	27.4	27.3	26.7	27.3	26.6	25.6	26.5	26.0	28.3	26.9	25.9	28.2
Mean temperature of surface water at Chrome Island during April through August of the downstream year (°C)	-	14.2	13.6	13.9	12.8	13.9	13.3	14.8	13.6	13.9	13.6	13.1	13.4	13.2
Mean temperature of surface water at Pine Island during January through March in the first winter at sea (°C)	7.9	7.0	7.9	7.8	6.7	7.6	7.3	7.2	6.4	7.9	6.8	6.0	7.0	6.9

[a] From 50% to completion of escapement.

[b] From 50% escapement to 50% fry migration.

Appendix 64. Data used in regression analyses of Big Qualicum River chinook freshwater growth and survival, and fingerling survival to escapement, 1959-1972 broods.

	Brood year													
	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Freshwater rearing period[a]														
Min. daily discharge (m^3/sec.)	3.8	4.3	3.1	2.0	7.9	3.7	4.2	4.4	4.2	4.9	2.8	4.4	6.2	3.2
Max. daily discharge (m^3/sec.)	19.3	27.5	11.4	16.4	15.1	11.1	7.5	8.3	6.7	8.2	6.4	11.8	13.2	6.0
Mean daily discharge (m^3/sec.)	8.5	8.5	5.2	6.2	8.8	5.8	6.6	7.1	5.3	5.5	5.0	6.9	8.3	5.2
Max. water temperature (°C)	14.2	17.8	16.1	18.1	13.9	16.4	15.0	14.4	16.7	11.4	17.8	11.4	16.7	16.4
Mean water temperature (°C)	9.7	9.4	7.9	8.9	7.8	8.2	8.2	7.3	8.2	6.4	8.4	6.3	7.2	7.7
Fingerling biomass (kg)	-	-	178	396	184	287	163	156	85	601	255	210	413	147
Fingerling survival to escapement														
Mean salinity of surface water at Chrome Island during April through August of the downstream year (ppt)	-	26.7	27.4	27.3	26.7	27.3	26.6	25.6	26.5	26.0	28.3	26.9	25.9	28.2
Mean temperature of surface water at Chrome Island during April through August of the downstream year (ppt)	-	14.2	13.6	13.9	12.8	13.9	13.3	14.8	13.6	13.9	13.6	13.1	13.4	13.2
Mean temperature of surface water at Pine Island during January through March in the first winter at sea (°C)	7.9	7.0	7.9	7.8	6.7	7.6	7.3	7.2	6.4	7.9	6.8	6.0	7.0	6.9

[a] Temperatures and flows measured during March through May of the downstream year at camp bridge.

Appendix 65. Data used in regression analyses of Big Qualicum River coho freshwater growth and survival, and smolt survival to escapement, 1959-1972 broods.

	Brood year													
	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Freshwater rearing period[a]														
Min. daily discharge (m^3/sec.)	0.7	0.4	0.9	0.7	0.9	1.7	2.7	1.5	2.1	3.5	1.5	1.9	1.6	1.7
Max. daily discharge (m^3/sec.)	90.6	35.7	56.6	41.9	22.7	20.8	24.1	22.8	23.2	23.8	14.3	23.6	25.0	26.8
Mean daily discharge (m^3/sec.)	9.5	5.3	7.5	9.3	5.5	7.1	8.1	7.2	6.9	7.2	5.4	7.2	5.4	8.0
Max. water temperature (°C)	21.1	20.6	20.6	21.4	18.6	19.4	20.6	19.4	18.9	16.4	20.6	16.7	19.4	20.3
Mean water temperature (°C)	10.9	9.9	10.2	10.3	9.4	10.4	10.1	9.7	9.0	8.9	9.2	8.1	8.9	8.7
Smolt biomass (kg)[b]	244	174	228	-	416	349	-	-	496	520	146	314	469	342
Smolt survival to escapement														
Mean salinity of surface water at Chrome Island during April through August of the downstream year (ppt)	26.7	27.4	27.3	26.7	27.3	26.6	25.6	26.5	26.0	28.3	26.9	25.9	28.2	26.6
Mean temperature of surface water at Chrome Island during April through August of the downstream year (°C)	14.2	13.6	13.9	12.8	13.9	13.3	14.8	13.6	13.9	13.6	13.1	13.4	13.2	12.8
Mean temperature of surface water at Pine Island during January through March in the first winter at sea (°C)	7.0	7.9	7.8	6.7	7.6	7.3	7.2	6.4	7.9	6.8	6.0	7.0	6.9	6.7

[a] Measurements of flow and temperature from May of emergence year to May of downstream year at camp bridge.

[b] Big Qualicum River smolt biomass of the 1959 and 1960 broods was calculated assuming 4,500 system migrants of each brood originated in Hunt's Creek.

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